Regional Integrated Program for Irrigation and Fertilization Management Assistance in Santa Clara, San Benito, Santa Cruz, Monterey, and San Mateo Counties

Project Report

Agreement No. 04-143-553-0

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- Final Report on Practice Effectiveness Monitoring by Dr. Michael Cahn, et al
- Application of the DNDC Model for the Regional Integrated Program for Irrigation and Fertilization Management Assistance by Applied Geosolutions, LLC

I. PROJECT DESCRIPTION

The project generally consisted of protecting and improving water quality in the targeted watershed and receiving coastal waters, including the Monterey Bay National Marine Sanctuary, by reducing agricultural nonpoint source (NPS) discharges and nutrient loading in Monterey, San Benito, San Mateo, Santa Clara, and Santa Cruz Counties through monitoring of practices and education of local growers with regard to irrigation practices and nutrient management.

NPS discharges and nutrient loading are water quality problems along the Central Coast of California. Agriculture is one of the primary sources of groundwater nitrate contamination and nutrient loading into surface waters that drain into receiving waters including the Monterey Bay National Marine Sanctuary. Agriculture on the Central Coast of California is intensive due to the high value of the commodities produced and the number of crops grown per season. To assure optimal yield and quality, growers apply high rates of fertilizer and water to their crops. Consequently, irrigation run-off and deep drainage from agricultural land has impaired the quality of ground and surface water. Irrigation run-off transports suspended sediments, nutrients, pesticides, and bacterial pathogens into surface water, and deep percolation leaches nitrate into ground water aquifers.

Currently, there is a great deal of interest in the agricultural industry to improve management practices to improve water quality. However, there are limited public and private resources to facilitate these goals. Therefore, this project has been designed to help growers improve irrigation and fertility management practices in Monterey, San Benito, San Mateo, Santa Clara, and Santa Cruz Counties. The specific project goals were (1) outreach and education on irrigation and nutrient management and (2) improve efficiency of grower irrigation and nutrient management practices.

II. PROJECT SCOPE OF WORK

The project began on December 1, 2004 and was completed April 30, 2007. The agreement between the State Water Resources Control Board (State Water Board) and the Santa Clara Valley Water District (District) specified the following scope of work:

- Contracts and Permits
- Quality Assurance Project Plan (QAPP) and Monitoring Plan
- Regional Program Advisory committee (RPAC)
- Education and Outreach to Recruit Growers to Participate in the Program
- On-Farm Consultation Services
- Sampling
- Reporting

All the projects tasks have been completed. The appropriate submittals have been provided to the Grant Manager at the Central Coast Regional Water Quality Control Board (Regional Water Board) as attachments to Quarterly Progress Reports.

III. PROJECT SUMMARY

This section describes and summarizes key project tasks, including methods and results.

A. Regional Program Advisory Committee

The Grantee formed a Regional Program Advisory Committee (RPAC) early in the project. RPAC, which consisted of Agricultural Water Quality Coordinators and water agency staff from the project area. RPAC's role was to provide insight and advice to the Grantee on project implementation. Because the project area encompassed five counties, RPAC served as a critical link in designing a program that would meet the needs of growers in five counties, with a variety of crops and field sizes.

Early RPAC meetings focused on determining how to best provide on-farm consultant services and developing the program outreach materials. Mid-project meetings usually included a review of how well services were being provided to growers, upcoming outreach and education events, and reviewing project status. Toward the end of the project, the RPAC discussed strengths, opportunities for improvement, and gaps in the project. Contractors were invited to participate more in RPAC toward the end of the project and, in hindsight, should have been included more throughout the project. Through most of the project, RPAC met monthly, rather than the three times per year specified in the grant agreement.

RPAC's feedback and insights were instrumental in delivering a successful program to growers in the five-county project area and making mid-program corrections and improvements. In addition, RPAC provided an opportunity to develop relationships between agencies and organizations that will strengthen future collaborative efforts.

B. Outreach and Education

The outreach and education tasks were described in the grant agreement as the method by which growers would be enrolled in the program. In accordance with the grant agreement and in consultation with RPAC, the Grantee created a program website, established a toll-free phone number, prepared an informational program brochure in English and Spanish, offered workshops and growers meetings, and offered a groundwater production charge discount to growers in Santa Clara County. In addition, the Grantee contracted with the Central Coast Agricultural Water Quality Coalition (Coalition) to perform outreach and education activities.

The program website and toll-free number were rarely used. The brochure created by the program was useful for advertising the program. The main sources of program information for growers were the Coalition's Ag Water Quality Coordinators (Coordinators). They did nearly all the work associated with recruiting growers, including distributing the program brochure and obtaining landowner access agreements. They also scheduled many of the growers meetings and workshops. The Coordinators were critical to the success of the outreach and education activities. The Coalition and Coordinators are an excellent resource for communicating with growers.

A number of growers meetings and workshops were organized by the Grantee and participating and cooperating agencies, Farm Bureaus, and organizations to provide education and training to growers on topics related to irrigation and nutrient management. Topics included annual irrigation and nutrient management meetings, fertigation workshops, and crop specific (i.e., peppers, chrysanthemums, Brussels sprouts) workshops. These meetings and workshops were in addition to watershed working group meetings, Farm Water Quality Planning courses, and Farm Bureau meetings that also provided educational opportunities. Based on surveys of growers, growers found field demonstrations to be the most useful training opportunity (2006 Growers Survey).

C. On-Farm Consultation Services

A total of 91 growers participated in the program during the two year program period. Three types of on-farm consultation services were provided – irrigation system evaluations, pump efficiency tests, and nutrient monitoring and management. A total of 83 growers received irrigation system evaluations, 88 growers received pump efficiency tests, and 69 growers received nutrient monitoring and management services. Not all growers received services both years, though the vast majority did, and not all growers received all services. The table below summarizes grower participation in the Project.

County	Total Growers	Irrigation Evaluations	Pump Tests	Nutrient Monitoring
Monterey	33	28	33	22
San Benito	9	9	9	8
San Mateo	19	16	16	15
Santa Clara	15	15	15	12
Santa Cruz	15	15	15	12

The following sections summarize work performed by and results reported by the on-farm consultation service providers. It should be noted that some of the observations and results are based on information provided by growers and/or limited duration monitoring and testing. However, several observations are reported by more than one contractor and highlight areas where further work could be performed.

1. Irrigation System Evaluations and Pump Efficiency Testing

The pump efficiency tests and irrigation system evaluations were performed by one contractor (Power Services) for both the 2005 and 2006 seasons. Power Services' report for 2006, which includes observations from the 2005 season also, is in Appendix A and summarized here.

Pump efficiency testing was performed based on methods established by the Cal Poly San Luis Obispo Irrigation Training and Research Center (ITRC). Power Services found that pump repairs would save a substantial amount of energy that would help fund some of the need system repairs. There are programs available to PG&E customers to help pay for these repairs. The contractor forwarded this information to interested growers.

Irrigation system evaluations were performed according to the procedures developed by ITRC, though methods and measurements differ according to system types. Irrigation system evaluations included a pump test. The irrigation system evaluation results presented to the grower included calculations of irrigation efficiency and distribution uniformity, based on data provided by the grower and measured in the field, and recommendations for improving both. Power Services reported irrigation efficiencies ranging from 60% to 1,367% and distribution uniformities ranging from 23% to 99%.

Power Services found that maintenance is main problem with the irrigation systems they tested. Flushing and repairing buried drip lines and replacing nozzles and gaskets on hand move sprinklers would have helped growers improve distribution uniformities and irrigation efficiencies.

Power Services, as well as the nutrient monitoring and management contractors, observed under-irrigation. Power Services and JMLord (the 2006 nutrient contractor) found that under-irrigation (applying less water than is required to meet ET_c requirements) was more prevalent than over-irrigation. Power Services estimated a potential water savings of about 200 acre-feet of water per year from the fields that over-irrigated.

JMLord also estimated large potential savings for nurseries where irrigation efficiency could not be measured, based on water applied during the evaluation.

2. Nutrient Monitoring and Management

Nutrient monitoring was performed by one contractor in 2005 (Buchanan Associates) and another in 2006 (JMLord). The scope of work for each contractor included holding initial meetings with growers, developing field-specific work plans, collecting and analyzing water samples from the grower's water supply, collecting and analyzing pre-plant soil samples, collecting and analyzing soil and plant tissue samples during the growing season, post-harvest soil nitrate profiling, and final reports to growers. In addition, both contractors asked growers to record fertilizer and water applications throughout the season. Buchanan Associates also collected runoff water quality samples from some fields. It should be noted that both contractors reported that their contracted scope of services did not provide for the needs of all crops types, most notably greenhouses/nurseries and tree crops, and that the contracted scope of work limited their ability to provide services that responded to each grower's unique management needs. Each of the contractors' reports are included in Appendix A and summarized below.

2005 Season

Buchanan Associates observed that many row crop fields had higher than necessary nitrogen (N) levels in soil either prior to planting or during early crop establishment. This trend was more consistent in fields where crops were planted late and in double-cropped fields. The trend is attributed to residual N release from incorporated crop residues and soil organic matter. Under these conditions and where pre-plant N was also applied, Buchanan Associations noted that N losses due to leaching are likely due to the small root system and crop N requirements. A number of row crop fields appeared to have adequate residual nitrate-N for early crop establishment.

Buchanan Associates also noted some instances of consistent over-fertilization in a few short and long-season vegetable fields under both sprinkler and drip irrigation. In the short- and medium-term crops, particularly where color is a market quality indicator, higher than optimal post crop residual soil nitrate levels were observed. In long-term cool and warm season crops, post crop residual soil levels were lower, but in-season leaching appeared to have occurred.

Buchanan Associates noted that irrigation water management is a critical variable influencing in-season nitrate leaching potential in the Region, especially in fields with predominantly sandy texture. They note that irrigation scheduling presents more operational variables for growers than fertilization due to noncontiguous fields, variability in the use of timers at wellhead, and variability in irrigators' levels of knowledge and experience. Further, based on discussions with growers, available irrigation records, and field data, there is some evidence that current drip irrigation management practices can enhance deep percolation of water and nitrate as a result of long duration applications that allow for deeper water movement past the root zone. More frequent, shorter applications may limit movement of water and nitrate past the root zone.

Buchanan Associates made an effort to highlight phosphorus (P) status in crop tissue as a means to discuss current concerns related to P in runoff and sediment from farm fields. All but one field had adequate to excessive levels of soil P. Fields in the northern portion of the region tended to have the highest soil P levels. Generally, growers were unaware of the potential cumulative effect of annual P applications and many growers were unaware of the soil pH effects on soil P availability.

Growers do not explicitly adjust N fertilization programs for fields that are irrigated with high nitrate well water. Although Buchanan Associates reported to growers that high N levels in crop petioles and leaves were consistently observed in fields irrigated with high nitrate well water, they also note that there is not an adequate body of crop research to provide guidelines on the potential availability of N in irrigation water.

Buchanan Associates incorporated tail water sampling and analysis into their program for interested growers. The results indicate that runoff water quality is directly related to fertigation through sprinklers. When and where fertigation occurred, nitrate-N in runoff consistently exceeded 10 parts per million. Buchanan Associates' follow-up discussions with these growers included identification of alternative fertilization practices to reduce potential nitrate loading.

2006 Season

The JMLord report presents 2006 data and findings collected through the Regional program, as well as though the local program sponsored by District. In summary, they found growers tended to under-irrigate, but almost a third of the monitored fields had higher nitrogen concentrations in the soil at the end of the season than at the start. Variability in crops, production goals, and production systems all affect how fertilizer is used. The project scope did not allow for addressing all fertilization management issues, but did identify areas where growers can potentially reduced production costs and water quality impacts.

The following table summarizes fertilizer application reviews of the 2006 season:

County	# Farms Reporting[1]	# Farms with Excess Nitrogen (N)	Excess N Applied (pounds/acre)
Monterey	13	9	92
San Benito	7	3	21
San Mateo	13	8	81
Santa Clara	39[2]	14	49
Santa Cruz	4	4	79
All Counties	76	38	64

The lettuce crop had the largest different between pre- and post-crop soil samples, with an increase of nearly 40 pounds per acre (lb/ac) Further, second foot samples contained nearly the same level of N as the first foot samples, indicating that N is most likely moving through the soil profile and below the root zone.

JMLord noted difficulties in monitoring and evaluating both irrigation and fertilization in greenhouse/nursery operations. Water often leached N from plant containers, creating a N deficit and necessitating additional N-fertilizer application.

JMLord also observed the use of cover crops and their impacts on nutrient availability, but noted that the impact of cover crops on nutrient budgets was not addressed by this Project.

JMLord noted the many growers did not provide yield data for their crops and that the data is important when evaluating nutrient usage during the crop cycle. A complete nutrient balance is not possible without accounting for the nutrients that were removed in crop residue.

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[1] Includes 15 farms that did not apply any fertilizer

[2] Includes growers from the District's local program

> JMLord reported that the nutrient monitoring portion of the program was very beneficial to growers, as it demonstrated that there more sources of nitrogen to consider than just commercial fertilizer and sparked growers' interest in learning how to improve nutrient usage for their crops.

This project task also included surveying growers on their irrigation and fertilizer management practices and record keeping. The survey was performed annually by the Coalition's Coordinators. The Coalition's 2006 Grower Survey results, included in Appendix A, indicate that most growers found the program worth their time and to be worthy of even greater investments of time. Most growers (91%) would like to see another program in the future. The Coalition's survey also found that 1/3 of growers reported that they reduced their fertilizer use as a result of contractors' recommendations and about 20% of growers reduced their number of irrigations. Lastly, 85% of growers found record keeping useful in their farming operation and more than 1/3 of the growers began or continued keeping records during the program.

D. Monitoring and Modeling

The objective of the monitoring and modeling work was to compare water quality and nutrient loading from vegetable fields under current, standard practices and under best management practices for water and nutrients. The work was performed under a contract between the District and the University of California. The project team was led by Dr. Michael Cahn, University of California, Cooperative Extension (UCCE) and included Drs. Marc Buchanan (Buchanan Associates), Changsheng Li (University of New Hampshire), William Salas (Applied Geosolutions), Neda Farahbahkshazad (Applied Geosolutions), and Marc Los Huertos (California State University, Monterey Bay).

During 2005 and 2006, adjacent fields or blocks at five sites in the project area were managed under different water and nutrient management strategies. Grower standard practices were applied on one field/block and best management practices were applied on the other field/block. Best management strategies included CIMIS weather-based irrigation scheduling, reduced N fertilizer applications, polyacrylamide for improving the quality of irrigation run-off, reduced applied water, subsurface drip irrigation, and fertigation of N fertilizer. Monitoring methods included evaluating irrigation efficiency, estimating crop canopy cover, monitoring soil moisture, estimating drainage, measuring runoff, monitoring irrigation runoff quality, monitoring soil nitrate levels, measuring crop yield and quality, and Denitrification-Decomposition (DNDC) modeling to estimate nitrogen losses.

Results of paired trails demonstrated that nitrate leaching losses could be reduced by using weather-based irrigation scheduling and soil nitrate testing to determine fertilizer-N requirements, and by supplying fertilizer and water in smaller but more frequent intervals than are usually used in commercial production.

The monitoring data is included in the "Final Report on Practice Effectiveness Monitoring" by Michael Cahn, et al, which is included in Appendix B. Appendix B also includes Applied Geosolutions' report on the DNDC modeling work.

IV. PROJECT EVALUATION

The goals of this project were outreach and education on irrigation and nutrient management and improved efficiency of grower irrigation and nutrient management practices for purpose of protecting and improving water quality in the Region. The monitoring results, as described above in Section III.D and presented in Appendix B, demonstrate that improved irrigation and nutrient management practices can reduce nitrogen loading. In other words, the best management practices are effective in preventing or reducing nonpoint source pollution.

A review of the project results compared to the targets in the Project Assessment and Evaluation Plan also indicates success in achieving project goals. The performance indicator targets were met or almost met in most cases, as summarized in the table below.

Project Task Category	Target	Actual
Education and Outreach	100 growers enrolled in the Project	91
	Increase the number of growers keeping records by 25%	38% began or continued to keep records, based on growers survey
	100% of growers recognize value in monitoring field conditions	92%, based on growers survey
Load Reduction; Beneficial Use Improvement and Protection	25% of growers reduce fertilizer use	34%, based on growers survey
	25% of growers irrigate based on crop needs	19%, based on growers survey
Load Reduction	Statistically significant decrease in runoff	Indeterminate, based on monitoring results, though runoff water quality was improved
Beneficial use Improvement and Protection	Statistically significant decrease in nitrate leaching	Yes, based on monitoring results

V. RECOMMENDATIONS

The following recommendations for future regional agricultural water quality programs are based on RPAC discussions and input from the on-farm consultation service providers (Power Services, Buchanan Association, and JMLord) and the monitoring and modeling team:

- **On-Farm Consultation Services**: Both Buchanan Associates and JMLord identified the need to have more flexibility in their scopes of work, so that monitoring could be tailored to individual grower's needs. The types of tests performed were limited by the contracts between the consultants and the Grantee. Also, there was no specific provision in the nutrient management contracts for providing irrigation scheduling assistance. Future programs should strive to have as much flexibility in the services provided to growers as possible, as opposed to prescribing a limited set of services from which a grower can chose.

- **Technical Assistance**: It is most helpful to growers to have direct access to people with expertise to answer their questions related to topics such as fertilizer types, application times, and irrigation scheduling. However, the region lacks a large pool of technical experts, such as UCCE Advisors, that can be called upon to provide technical assistance to growers. Future programs should consider a “train the trainer” component to develop technical expertise in the region.

- **Crop Groups**: It would valuable to develop projects and programs that recognize and respond to individual crop groups. For instance, permanent crops/orchards are managed very differently than short-season crops such as lettuce. Organic growers’ nutrient management needs are different than those using commercial fertilizers. Addressing crops types would help provide growers with information more specific to their issues. Two crops types are especially in need of future consideration.

  - **Nursery Operations**: Greenhouse/nursery operations have unique characteristics that warrant a different approach to irrigation and fertilization management, which were not adequately addressed with the scopes of services provided under this program. Nursery operations presented a unique challenge in tracking nitrogen usage, since watering often leaches the nitrogen from the plant containers. Likewise, their irrigation systems can present unique challenges. There should be a focused effort to address nursery operations, where there are significant opportunities for improvement in irrigation and nutrient management.

  - **Organic Crops**: Future projects should be considered to help organic growers develop nutrient management strategies and better understand how to estimate nutrient application, from sources such as manure, for organic crops.

- **Irrigation Scheduling**: Additional training on irrigation scheduling would be helpful, so more growers are able to use sound data to improve their water and nutrient use efficiency. The training should also highlight the relationship between irrigation/water management and water quality issues. One area of interest is the difference in water quality impacts from shorter, more frequent drip irrigation sets compared to longer, less frequent sets.

- **Cover Crops**: Training should be provided to growers on how cover crops can affect nutrient availability in future crop cycles and how growers can account for impacts in developing nutrient budgets.

- **RPAC**: The Grantee recommends that future regional agricultural water quality projects include an Advisory Committee with members from agencies, Farm Bureaus, universities, and other agricultural organizations such as the Central Coast Agricultural Water Quality Coalition. Individual agencies and organizations should maintain contacts with others in the region as a means of being able to locate resources, find synergies between projects, and coordinate on intra-regional programs.

- **Central Coast Agricultural Water Quality Coalition and Water Quality Coordinators**: The Coalition and its Coordinators are a valuable resource for recruiting growers into programs, conducting outreach for workshops and meetings, and providing a link between the growers and project/program managers.

- **Field Demonstrations**: Future programs should integrate field demonstrations into their education activities. Growers prefer field demonstrations over meeting hall workshops and tailgate workshops for training opportunities. Field demonstrations also provide cooperating growers with one-on-one consultation services tailored to their project.

- **Gasket & Nozzle Exchanges**: Water use efficiency is typically improved with irrigation system maintenance. Gasket and nozzle replacement is one maintenance area that growers could improve in. As a means of facilitating improvements, a future program could incorporate an exchange program. Growers would bring in their old gaskets and nozzles and leave with new ones.

- **Phosphorus**: Phosphorus is significant water quality issue. Future programs should include more outreach and education regarding factors that influencing phosphorus availability and its environmental fate.

APPENDIX A

On-Farm Consultation Service Documents

Five County Regional Program: Mobile Irrigation Lab Program by Power Services, Inc

Regional Mobile Agricultural Lab: Nutrient Management Program 2005 Season by Buchanan Associates

2006 Program Summary Report: Infield Nutrient Management Assistance Program by JMLord, Inc.

2006 Growers Survey Report by Central Coast Agricultural Water Quality Coalition

APPENDIX B

Monitoring and Modeling Documents

Final Report on Practice Effectiveness Monitoring by Dr. Michael Cahn, et al

Application of the DNDC Model for the Regional Integrated Program for Irrigation and Fertilization Management Assistance by Applied Geosolutions, LLC

APPENDIX A: On-Farm Consultation Service Documents

Power Services, Inc

Five County Regional Program

Mobile Irrigation Lab Program

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Five County Regional Mobile Irrigation Lab Program

1. Executive Summary

Background

The Five County Regional Program (FCR) conducted a two (2) year program to provide irrigation and nitrogen management (Mobile Irrigation Lab Services[1]) information to the growers in Santa Clara, San Benito, Santa Cruz, San Mateo and Monterey Counties. The objective of the program was to reduce nitrogen loading to water resources through improved water and fertilizer use.

The State Department of Water Resources developed the “Mobile Irrigation Lab” concept as a way to better reach California growers with new water management techniques and to evaluate their current practices. At this time there are currently 6 Mobile Irrigation Labs in the state that cover 15 to 18 counties in the San Joaquin Valley, the Coachella Valley/Southern Desert, and the Central Coast regions. Power Services, Inc. is the Mobile Irrigation Lab used in 8 of those areas.

This report documents the Tasks and Accomplishments of the second year of the FCR Mobile Irrigation Lab Program and provides data to illustrate where the potential water savings can be found.

Objectives

The primary goal of this program is to improve water and fertilizer use efficiency by the growers in the Five County area. Water conservation and nitrate management is very important to the counties and all of their constituents. The Mobile Irrigation Lab, which works directly with growers on their farms, demonstrates proven management techniques and is an effective way to promote these goals.

Results

A total of 88 evaluations were made in 2006 for orchard, row crop, vineyard, and nursery irrigation utilizing the following systems:

- Drip on Vines and Nursery Crops
- Buried Drip on Row Crops
- Micro Sprinkler on Trees and Nursery Crops
- Permanent Undertree Sprinkler
- Aluminum Hand-move Sprinkler on Row and Nursery Crops
- Furrow on Row Crops
- Linear Move on Row Crops

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[1] Based on the State of California approved “Cal Poly Method”, irrigation evaluation technique and software program developed at Cal Poly San Luis Obispo.

In 2005 we noted that Five County growers tended to under irrigate. In the 16 years that we have been conducting irrigation system evaluations we have found that most growers don't add the water needed to make the distribution uniformity (DU) 100%. This is often done by the grower because of the high cost of water and/or electricity. In most years there is minimal impact from this practice due to stored rainwater in the soil profile. In drought years this practice tends to leave salts in the root zone of the crops.

Information provided by each grower at the time of the test provides an estimate of total water to be applied to any one crop. Results from system evaluations in 2006 followed historic trends. Of the 88 systems tested for FCR in 2006, 52 (59%) seemed to slightly under irrigate, while 31 (35%) appeared to potentially over-irrigate.

Vine Crops

In 2006 the all of fields evaluated were drip systems. These systems achieved DU values ranging from 82 to 92 percent.

Orchard/Tree Crops

There were only three systems evaluated this season, which were Drip, Undertree and Micro sprinklers. These systems achieved DU values ranging from 84 to 99 percent. The systems were all in good shape with excellent DUs.

Row crops

Many of the row crop growers that we worked with are using buried drip. These systems achieved DU values ranging from 62 to 96 percent.

In sprinkler system evaluations we observed common problems related to leaking gaskets and/or mixed nozzle sizes. These systems had measured DU values ranging from 23 to 93 percent.

2 fields had Linear Move systems with DU's of 90 and 91 percent

There was one furrow test that had a DU of 68%. The lower DU was due to very uneven advance times related to variable compaction in furrows and low application volumes per unit time.

Nursery Crops

During the 2006 growing season we tested 13 systems for nurserymen in the FCR. Many of the systems were potted plants and we were unable to determine the Irrigation Efficiency. The DUs ranged from some of the best to some of the worst. Nurseries are a special breed and offer a great potential for savings

2. Tasks and Products

Task List

Six tasks were carried out for the 2006 Mobile Irrigation Lab Program; these tasks are listed along with their product in the table below.

Table 1. Mobile Irrigation Lab Program Tasks and Products

Task	Performed By	Product
1. Obtain Grower List	County Coordinator	Lists Obtained
2. Screening	Project Manager[2]	Final List Obtained
3. Field Work	Power Hydrodynamics	Completion of Field work
4. Irrigation System Reports	Project Manager	Customers System Reports
5. Follow-up Visits	Power Hydrodynamics	Completion of Program Survey
6. Annual Report	Project Manager	Annual Report

Tasks 1 - Marketing and Customer Contact

The local Agricultural Water Quality Coordinators (County Coordinators) were responsible for marketing the Mobile Irrigation Lab Program to the growers. This was done through a series of workshops designed to inform the growers about the Mobile lab program and nitrate management. At each of the workshops a list was circulated for the growers to sign up to participate in the program. This process generated a list of 86 growers.

Task 2 – Screening

The list of growers was faxed or emailed to the Power Hydrodynamics Project Manager so he could start the screening process. This consisted of contacting the grower on the telephone to determine if the grower was truly interested. Out of 86 that signed up, 13 were dropped due to the fact that they changed their minds and no longer wanted the test. The final list included 73 growers with operations ranging from 10 to over 600 acres. From this list we set up and completed 88 system evaluations (Table 2).

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[2] William Thomas Power, III Project Manager for Power Services, Inc.

Table 2. Number of field tests and total acreage for each of the 4 system types evaluated during 2006

System type	# Evaluations	Acres Evaluated
Hand move Sprinkler	38	535
Undertree	3	119
Drip/Buried Drip	42	360
Furrow	1	10
Linear Move	2	41
Micro sprinkler	2	21
TOTAL	**88**	**1086**

Tasks 3 and 5 - Field Work and Follow-up Visits

Each grower was given one or more system evaluations depending on the growers need. A grower with multiple fields and irrigation systems received as many tests as the County Coordinator and the Power Services, Inc. Project Manager felt were necessary to help the grower. Irrigation system evaluations were performed according to the procedures developed by Cal Poly SLO for the Department of Water Resources (Burt et. al., 1995), along with a PG&E style pump test on each field to assess the performance of the irrigation equipment at the site.

Overall Plant Efficiency (OPE) measurements require data on the total lift, input horsepower of the pump, as well as, a measurement of actual flow rates. Data on pump performance specifications are obtained from nameplates on the pump housing, pipe inside diameters are measured, and a manometer is installed prior to starting the pump. Water velocity, pressure, amperage and voltage draw are measured. Where possible well water levels are taken during pumping and 5 to 10 minutes after the pump has been shut down.

Irrigation System Evaluation methods and measurements differ for each system evaluated:

Aluminum pipe sprinklers

Catch cans are placed in a grid in the field around sprinklers to determine how evenly the water is distributed. Pressure and flow rates are also measured at each of 12 sprinkler heads for a duration of one minute. The location of these measurements is determined by the software and is similar in all system evaluations distributed over points close to and at the furthest distance from the pump.

Drip/Micro-sprinklers

Measurements are made of emitter uniformity (EU) as opposed to DU measured with catch cans. Water is collected from a total of 76 emitters in three locations (closest, mid, and farthest from the pump). Pressure measurements are made throughout the system.

Under-tree/Over-vine

The system test requires measurement of the flow and the pressure at the sprinkler heads across the field. This test is similar to the drip test. We look for flow variations and pressure drops that would indicate a problem with the hardware and evaluate the amount of time that the system is run to see if there is a problem with the irrigation schedule.

Furrow

The test of furrow systems requires measurements of furrow length, determination of whether the furrow is a wheel row or non-wheel row (did the tractor drive in that furrow or not) and the amount of time the crop-received water. This last determination is called the Advance/opportunity time. When you furrow irrigate you want to get the water across the field as quickly as possible but not so fast that you create a large amount of run-off. The perfect furrow irrigation starts with a large head of water then cuts the head back so a small amount of water is running off the field for the duration of the irrigation (this is called cut-back irrigation). Neither of the two fields we tested used this method.

Linear Move

These systems are tested in much the same way you test a Handmove system. Catch cans are placed in a grid in the field in the path of the Linear Move to determine how evenly the water is distributed. Pressure and flow rates are also measured at each of 12 sprinkler heads for a duration of one minute. The location of these measurements is determined by the software and is similar in all system evaluations distributed over points close to and at the furthest distance from the pump.

Each grower was mailed the evaluation report and a direct follow-up meeting was scheduled with the grower after he/she had an opportunity to review the material.

Each field test, including system evaluations and pump test, required an average of four hours. Data entry and computer analysis required an additional hour per system. The time required for subsequent follow-up meetings with growers ranged from 0.5 to 1.5 hours, depending on the number of fields evaluated for each grower participant.

Tasks 4 and 6 - Reports

A *System Evaluation Report* was prepared following the field test. The report provides a summary and recommendation section and a detailed print out of field and pump test results. The summary sheet provides calculations for the Irrigation Efficiency (IE) and Distribution Uniformity (DU) as defined by Burt (1986).

Irrigation Efficiency or ‘on-farm irrigation efficiency’ is defined and calculated as:

$$IE = \frac{\text{Water Beneficially Used}}{\text{Water Applied}} \times 100$$

The total amount of water applied during any irrigation set is determined by multiplying the measured flow rate by the duration of the set. Water applied by the irrigation system may be lost as evaporation, spray loss, runoff or transpiration, be stored in the soil root zone, or be lost to the root zone through deep percolation. This is estimated by accounting for sprinkler head flow rates, measurement of water potentially landing on the soil surface, the average published infiltration capacity (from USDA Soil Surveys) for the specific soil type, and visual confirmation of runoff during the irrigation run.

Distribution Uniformity describes how evenly water is made available to plants throughout a field and has been defined and/or calculated by several methods. One definition is based on the variations in actual average water infiltration into soil. In practice it is easier to use catch can (sprinkler system evaluation) or emitter delivery measurements (drip systems) as the basis for calculating DU. From these methods the Cal Poly evaluation software calculates DU as:

$$DU = \frac{\text{Average of lowest 1/4 of intercepted water}}{\text{Average of all water flows,}} \times 100$$

There are a number of factors that influence DU but are difficult and mathematically complex to incorporate into such a diagnostic approach. For sprinkler systems DU is most influenced by sprinkler lateral spacing, pressure differences, pipe leakage, and worn and plugged sprinkler nozzles. For drip systems pressure differences, emitter plugging, manufacturing variations and age of materials affect DU.

Pump Plant Efficiency is calculated based on the measurements described previously (flow rate, total lift and input horsepower) by the following:

$$\text{Hp} = \frac{\text{GPM x (feet of pressure)}}{\text{3960 x (Pump Efficiency/100) x (Motor Efficiency/100)}}$$

This *Annual Report* recaps the efforts of the past year and serves as the final Product delivered under the FCR Mobile Irrigation Lab Program.

3. Results of the 2006 Mobile Irrigation Program

Irrigation Systems Used in the Five County Region

There are seven principal types of irrigation systems that were evaluated in 2006:

Aluminum Hand-move Sprinkler on Row and Nursery
Buried Drip on Row Crops
Furrow on Row Crop
Linear Move on Row Crop
Drip on Vines
Permanent Undertree Sprinkler
Micro Sprinkler on Trees

Aluminum hand-move sprinklers are set up and run the same way for all crop types, so they are listed together for this report. The following is a brief description of the systems, measured DU values, and a short discussion of some of the most common problems associated with them.

Aluminum Hand-move Sprinkler on Row, Nursery and Vine Crops

This is the system type used on the largest number of acres in the program. The larger growers tend to do a better job of replacing worn nozzles and gaskets but because of the large number of sprinkler joints used, this is the next best place to realize water savings. This pipe was made for this application and when workers lay the pipe out they usually get sprinkler-to-sprinkler coverage and a fairly good DU.

The systems tested in 2006 achieved DU values ranging from 23 to 97 percent. In comparison to 2005, where the least efficient system was 42 percent, we found many systems (12) that were measured at 60 percent and lower. Some of these (3) were due to windy conditions, but the remaining were poor due to low pressure at sprinkler heads, bad gaskets, worn nozzles, and/or mixed nozzle sizes.

Buried Drip on Row Crops

Drip is a low volume system that delivers around 0.5 gallons per hour (GPH) through drip emitters directly to the ground, but the hose is replaced by thin walled disposable tape. The spacing is usually 1 foot and depending on the crop, you would use 1 or 2 hoses. The tape is designed to be buried at 8-10 inches and left in the ground for several years. However, many growers now bury it 1 or 2 inches and replace it every year. The main reason for this is due to gopher damage and ‘tractor blight’ (damage from cultivation). The tape is much easier to repair close to the surface.

Many of the row crop growers that we worked with are using buried drip. The systems tested in 2006 achieved DU values ranging from 49 to 96 percent. Obviously this should translate into significantly greater yield potential over hand-move sprinkler systems. However the high cost of a buried drip system combined with the fact that many of the growers in FCR are on leased ground makes irrigation with aluminum pipe sprinklers the preferred method for many growers. Systems that had measured DUs below 80 percent typically had problems related to poor design/layout or imbalances related to pressure valves.

Drip on Vines and Nursery Crops

This system is similar to the above, but utilizes heavier walled tape to deliver water on the ground right above roots of the tree or vine. On vines there is usually 1 hose with emitters built into the tube spaced every 3 feet, while on nursery crops there are button type emitters at the plant (sometimes on the end of spaghetti or ¼ inch tube) that tends to be drastically over sized. These systems run for short time periods very often. A good average would be 6 to 12 hours every to every other day. The premise behind this system is to replace the water used by the plant each day. These systems are also very good at reducing the amount of fertilizers needed in the field as the plants are spoon fed the fertilizers instead of them being spread out over the entire field. The DU in drip is actually the emitter uniformity (EU) and is a measure of how well the emitter was manufactured and maintained after installation.

In 2006 we tested ten systems, which had DUs ranging from 65 to 96 percent. However we found that, in most cases, these systems were being operated inefficiently and, therefore had a less than optimal IE. In particular, we found that the wine grape growers were dramatically under-irrigating their crop.

Permanent Undertree Sprinkler

This is the old standard for orchards. The sprinklers (usually impacts) are installed throughout the orchard at specific points based on a mathematical design. The concept is to use the least amount of sprinklers (1 sprinkler for 3 to 6 trees) yet still cover the entire orchard floor with water. This utilizes sprinklers that put out 2 or more gallons per minute (GPM), an amount that quite often exceeds the infiltration rate of the soil. It is my observation that most of these growers run their systems 24 to 48 hours, once every 2 to 4 weeks. This type of irrigation schedule can stress the trees twice each irrigation cycle—once from the soil profile being saturated right after the irrigation event and then due to a dry soil profile prior to the irrigation event. The Cal Poly SLO Irrigation Training and Research Center (ITRC) recommends that growers should treat their undertree systems like a micro system and make smaller water applications more frequently.

A total of three systems were tested in 2006 with measured DUs ranging from 95 to 98 percent, with an average of 96.5 percent.

Micro Sprinkler on Trees

Micro sprinklers are another low volume delivery system used on tree crops that average 10 to 20 GPH per emitter with 1 emitter per tree. This system is basically a high volume drip system that puts the water out over a larger area but still doesn’t cover the whole orchard floor. This type of system in my mind is the best for orchards. Micro sprinklers put the water and fertilizer on the trees root zone where it is needed and reduce the run-off and evaporation losses that can happen with an undertree sprinkler system.

Only two systems were tested in 2006 with an average DU of 81 percent.

Furrow

Furrow irrigation was the main form of irrigation in California for years. Most of the growers in the area have switched to other irrigation system types and only use furrow to irrigate ground that is leased and doesn’t have the infrastructure to operate another type of system or as a high volume ‘catch up’ irrigation for ground that needs water fast.

The basic concept behind furrow irrigation is to advance the water evenly and quickly across the field and then maintain a flow down the furrow that gives all of the plants an opportunity to receive the water with out an excess of tail-water leaving the field. To accomplish this, the grower needs to start a certain flow down the furrow and adjust that flow after the water reaches the tail end of the field. This is called "cut-back" irrigation. Most growers do not do this. Most growers start with a smaller head of water (which causes longer advance times) and let the tail-water leave the field until the irrigation event is finished. This can cause a low DU. The longer your irrigation events are the higher your DU could be using this method because the longer run time over comes the uneven/slow advance times. The furrow was evaluated for one vegetable crop and had 68 percent. The system DU was lower due to uneven advance time for water down furrows. This was caused by the grower running a small head of water and different advance times in wheel versus non-wheel furrows on one field.

Linear Move on Row Crop

This type of system was designed to replace Hand Move sprinklers. They operate with the same sprinkler to sprinkler coverage down the line but in stead of a worker moving the pipes, the whole system moves slowly across the field resulting in a very high DU. The 2 system we tested in 2006 had DU's of 90 and 91 percent.

Evaluations Summary

Maintenance is once again the main problem with the irrigation systems we tested. Flushing and repairing buried drip lines and replacing nozzles and gaskets on Handmove sprinklers would have helped all of the growers achieve higher DU's and better IE's. Nurseries present the most opportunity for improvement, but at the same time, they are such a unique beast, that the changes needed may be cost prohibitive. There were several growers that need to look at system management and work on decreasing the amount of water applied. But a majority of the growers tend to under irrigate.

Pump repairs would save a substantial amount of energy that would help fund some of the need system repairs. There are program available to PG&E customers to help pay for these repairs. We forwarded this information on to the growers that were interested.

Potential Savings

Implementing the recommendations given by the Mobile Lab could possibly have saved the amount of water that was used in irrigation over and above what was needed, and water lost due to non-uniformity. The amount of energy that could have been saved is based on improving the overall pumping plant efficiencies and the energy used to pump wasted water. This is only an estimated amount based on information that was derived from a single event for each of the 88 systems evaluated.

Water

52 fields (59% of all tested) under irrigated, this means that 658 acre feet of water was saved due to deficit irrigation.

31 fields (35% of all tested) over irrigated, this means that there is potential to save an additional 247 acre feet of water.

There were also 5 (6% of all tested) nurseries that we could not determine an irrigation efficiency for, but we know that there is a large potential for savings based on water applied.

Energy

The attached spread sheet also gives the Pump Plant Efficiency and potential savings related to system improvements. Not all irrigation systems tested had electric pumps and some that did could not be tested. There were also 16 additional pumps that were tested without an irrigation system test. Potential savings are those that would be realized by improvements to not only the pump, but also other components and overall operation of these systems. This potential is 391,098 kWh or $70,397.63.

Pump Plant Efficiency is calculated by the following:

$$\frac{(1.024)\ (\text{Acre Ft.})\ (\text{Total Lift})}{\%\ \text{Overall plant efficiency}} = \text{kWh/yr.}$$

Note: At 100 % OPE; it takes 1.024 kWh to lift one-acre foot of water one foot.

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Regional Mobile Agricultural Lab

Nutrient Management Program

2005 Season

February 2006

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EXECUTIVE SUMMARY

The Regional Mobile Ag Lab – Nutrient Management Program (NMP) was initiated in May of 2005. The 2005 work tasks were largely based on a services template with the intent to provide grower clients with a detailed evaluation of their current or typical nitrogen (N) and/or irrigation management practices for a specific crop. Buchanan Associates (Contractor), with the assistance of Farm Bureau Coordinators, established field work plans with growers between May and August of 2005. Fieldwork was not initiated until June of 2005 and the final field project was concluded in late January 2006.

The Contractor held initial meetings with forty-one (41) potential grower clients, of which thirty-six (36) elected to receive NMP services. The Contractor made a concerted effort to accommodate grower client's specific requests for work and/or information included in each field or facility project scope. Following agreement on the project scope the grower was given an information packet that contained the Summary of Services factsheet, Contractor contact information, technical references related to irrigation and fertilization/fertigation (including background on CIMIS), and a standard record keeping form. Almost every work plan was developed during the initial meeting and in consideration of the specific interests or needs identified by each grower. The crops and irrigation systems evaluated represent a reasonable cross-section of the region and indicate the relative diversity within and between the various counties. Some general similarities in the nature and scope of field work plans occurred within crop types (nursery, tree, and row).

Soil Nitrate Monitoring - The majority of NMP field sampling activities were soil nitrate-N monitoring in the effective root zone of crops. In contrast to traditional pre-planting or post-harvest soil sampling for complete nutrient analysis, this monitoring approach is time and sample intensive. Many row crop fields had higher than necessary N levels in soil either prior to planting or during early crop establishment. This trend was more consistent in fields that were not planted until June where apparently N release from incorporated crop residues and soil organic matter was significant. This trend was also found in double cropped fields where the evaluation was performed on the second crop. Under these conditions and where pre-plant N was also applied, N losses due to leaching are likely due to the small root system and crop N requirement. Less frequent, but clearly documented with the evaluation protocols, were observations of consistent over-fertilization. This was not apparent (and expected) in any tree crop systems evaluated, but was observed in a few short and long season vegetable fields under both sprinkler and drip irrigation.

Irrigation Management - Analysis of results from field work and in reflection of discussions in the initial and final grower meetings, it is apparent that irrigation water management is perhaps a more consistently critical variable influencing in-season nitrate leaching potential in the region. This is particularly true in fields with soils of predominantly sandy texture in comparison to those with clay texture. Most growers typically face many more operational variables that influence decisions concerning irrigation scheduling, as opposed to fertilization. Only two growers in the 2005 NMP have experience with or use daily or weekly real time evapotranspiration data from weather stations. The growers who had experience or familiarity with either CIMIS-based scheduling, had at one time utilized advanced soil moisture sensing, farmed in the fog zone close to the ocean, or had spent more time adjusting scheduling with drip all appear to be using more effective irrigation schedules that limit movement of nitrate.

Crop Tissue Analysis - Most grower clients received an analysis and interpretation of crop nutrition as assessed by a whole leaf analysis, and where appropriate routine determination of fresh sap petiole nitrate. Generally petiole results largely supported soil nitrate-N monitoring revealing or confirming high or low soil nitrate availability, during the course of crop development. Total leaf N content and petiole nitrate analyses correlated very well, while many growers were more interested in calcium, potassium, and zinc nutritional status determined on whole leaf samples.

Complete Soil Tests - All grower enrollees received a complete soil test, unless they indicated that they regularly sample and analyze samples, or had a current soil test report for the field. Generally there were clear links between soil nutrient and leaf analyses. The most common concerns were about soil pH, calcium, potassium, and zinc status. With one exception, all fields evaluated had adequate to excessive levels of soil P. Fields in the northern portion of the region tended to have the highest soil concentrations of all areas. Generally most growers were/are not aware of the potential cumulative effect in soils due to annual P applications. All growers were informed of perceptions and concerns related to agricultural P loading in surface waters.

Irrigation and Runoff Water Tests - Concerns about irrigation water quality appear to be increasing, mostly due to overall salinity, bicarbonate, sodium, and chloride concentrations. These growers have not made any production responses to high nitrate concentrations in well water. There is a general awareness that high nitrate in well water can contribute to crop nutrition and potentially allow for lower N fertilizer applications. No grower explicitly adjusts their N fertilization programs for ranches or fields that are irrigated with high nitrate well water. However, it is still not possible to provide reliable guidelines for the potential availability of N in irrigation water that growers can implement as there is no adequate body of crop research to support this. Conversely, grower clients that utilize surface water diversions and impounded water have few to no production constraints related to irrigation water quality.

A few growers desired to evaluate tailwater nitrate. The results of this monitoring demonstrated that runoff water quality is directly related to fertigation through sprinklers. When and where fertigation occurred, nitrate-N in runoff consistently exceeded 10 ppm. Follow-up discussion with these growers included identification of alternative practices (e.g. time release fertilizers, vegetative treatments) to reduce potential nitrate loading.

Record Keeping - Much emphasis was placed in the original RFP and during the pre-bid discussions on grower record keeping. The Contractor reviewed the Record form with each client, discussed what type of record systems were all ready used, and emphasized the importance of the record for the NMP field and for the grower business in general. The Contractor only received five completed irrigation and fertilization forms from growers.

Grower Reports - All growers have received a formal written summary report. The reports integrate all field test results into a coherent assessment of the efficacy of N fertilization and irrigation management. The report also provides formal documentation of each grower’s participation in the NMP and provided a reference for discussions in the final meetings. Many noted that is was most helpful to have a printed report and the in-person review. In all cases the growers or managers indicated that there was value and reasonable rigor in the field methods.

Conclusions and Recommendations - This report includes a brief qualitative analysis of important trends observed related to nutrient and irrigation management. In conclusion a summary list of recommendations is also provided.

SCOPE AND OBJECTIVES

The Regional Mobile Ag Lab – Nutrient Management Program (NMP) was initiated in May of 2005. The 2005 work tasks were largely based on a services template with the intent to provide grower clients with a detailed evaluation of their current or typical nitrogen (N) and/or irrigation management practices for a specific crop. For most growers the nutrient evaluation also included a general assessment of complete soil and crop nutrient status, as well as irrigation water chemistry. Clients received a formal written report and an oral summary review in the winter of 2005-06.

Table 1. Regional NMP client and program deliverables

GROWER MEETINGS Initial Planning Evaluation Summary
RECORD KEEPING Irrigation Scheduling Fertilization
SOIL NITRATE-N MONITORING Residual Soil Nitrate at Planting - 3 to 5 foot soil depth Routine Soil Nitrate-N Estimates - Root zone and to 24 inches Post-crop Residual Nitrate - 3 to 5 foot soil depth
PLANT TISSUE ANALYSIS Fresh Sap Petiole Leaf Tissue
COMPLETE SOIL ANALYSIS Root zone sample
WATER ANALYSIS Irrigation (Well and surface) Runoff
GROWER MEETING REPORT FORMS Initial and Final Summaries
FINAL GROWER REPORTS Irrigation (Well and surface) Runoff
ANNUAL REPORT

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2005 WORK AND METHODS SUMMARY

Buchanan Associates (Contractor), with the assistance of Farm Bureau Coordinators, established field work plans with growers between May and August of 2005. Fieldwork was not initiated until June of 2005 and the final field project was concluded in late January 2006. A late contract start ultimately had some negative impacts on delivery of services, as a few projects began well after crop establishment and, in two cases, potential clients felt that it was too late in season to start and complete any meaningful work on their desired crop. The Contractor was also further delayed in establishing grower contact due to difficulties in determining service requests from the first few iterations of the Grower Contact spreadsheets.

Prior to the initial meetings, the Contractor determined that a Summary of Program Services ‘fact sheet’ was needed and this was developed with help of the Administrator. At the initial visit, the Contractor provided a summary sheet indicating the general template of services offered. In many cases it was found that potential grower clients were not aware of the Program’s intent or specific services. Four growers elected not to receive NMP services.

Initial Grower Meetings

The Contractor made a concerted effort to accommodate grower client’s specific requests for work and/or information included in each field or facility project scope. During an initial meeting the Contractor established the following: farming history, size of operation, crop mix, fertilization and irrigation practices, location of project field and water sources, any current production issues, past incidence of soil-borne diseases, typical production on a per acre basis, and other important production information. Following agreement on the project scope and, in most cases, projected planting date the grower was given an information packet that contained the Summary of Services, Contractor contact information, technical references related to irrigation and fertilization/fertigation (including background on CIMIS), and a Recordkeeping form (See Appendix I).

Record Keeping Form - Most growers were asked to maintain irrigation and fertilization data or transfer data from their existing record format to this sheet. The Contractor informed each grower that this information would be used in order to further assess grower’s irrigation scheduling and allow the Contractor to compare their practices to an example schedule based on actual CIMIS or other average Eto data for their area. In a few cases, growers provided reasonable reasons why they would not or could not gain any value from such a comparison.

N fertilization - The grower was asked a series of questions regarding past and present practices, field by field and crop by crop. The Contractor attempted to determine the grower’s basis (e.g. experience, established guidelines, vendor or PCA recommendations) for current practices and how the grower evaluates the success of fertilization practices (other than market yield). Questions posed by the Contractor regarding N fertilization included not only quantity per crop, but rationale for use of certain N fertilizers and other materials, application methods and equipment (including drip fertigation), timing when split applications are used, and typical bulk handling, storage and transfer methods. The Contractor generally tried to limit the discussions to N fertilization, but a number of grower’s wanted information and analysis of other fertilization or soil nutrient availability issues The Contractor determined if the grower utilizes soil analysis as a management tool and further, whether the grower has the background/experience to fully interpret laboratory results and recommendations. The Contractor BA also discussed the importance of a comprehensive view of N sources including pre-plant residual N; crop residue N availability; cover crop N release; and/or the irrigation water nitrate-N. In some cases, a variety of monitoring tools were described, including the soil nitrate quick test.

Irrigation Management **-** The Contractor generally discussed irrigation scheduling practices and a very wide and diverse set of responses were provided by growers. Discussions included water sources (well or surface), irrigation technologies/methods used (drip, sprinkler, furrow), and any water quantity or quality issues. The Contractor attempted to determine the constraints and criteria used by growers in determining when and how much to irrigate. Further the grower was asked to provide their own evaluation of the efficacy of water applications, including typical maintenance and repair task schedules. The Contractor often utilized the technical information packet provided to initially evaluate the grower's familiarity with simple definitions of Eto, plant water requirement versus irrigation water requirement, and scheduling.

Field Work Plans

As noted previously almost every work plan was developed during the initial meeting and in consideration of the specific interests or needs identified by each grower. In some cases, the potential work plan did not follow the 'script' of the services template and required that the Contractor submit a plan outline for approval by the Administrator. In one case delays in approval prevented the Contractor's timely initiation of work (work flow management challenges) resulting in one grower not receiving services in 2005.

Table 2 summarizes the various cropping systems that received an NMP evaluation in 2005. The crops and irrigation systems represent a reasonable cross-section of the region and indicate the relative diversity within and between the various counties. Some general similarities in the nature and scope of field work plans occurred within crop types (nursery, tree, and row). All routine monitoring samples were collected from pre-determined and fixed, marked locations in each field. As fields on average ranged from 1 to over 40 acres, the minimum number of sample locations was five (5) and the maximum fifteen (15)

Tree crops – The late start completely eliminated any early season soil sampling, particularly deep profile sampling. Therefore no comparison of early to end of season residual soil nitrate-N could be provided. Typical data included one deep soil profile assessment (3 to 5 foot depths), a complete soil analysis of the rooting zone (typically 6 to 18 inches), and a complete nutrient analysis of a leaf sample. In two cases, prior knowledge and/or initial grower discussion, allowed for some sporadic soil moisture monitoring (with Contractor-supplied equipment) in order to get some insight into the efficacy of irrigation scheduling. Irrigation well water samples were collected when possible.

Row and Field Crops – Depending on crop type and duration more intensive soil and crop sampling was performed. For all row crops (with exceptions for prior established plantings) either pre-plant or early post-planting deep soil profile sampling was compared to post- or at harvest (3 to 5 foot depth). For short duration crops like lettuce or baby spinach soil sampling in the root zone (typically 0 to 12 inches) and below the root zone (12 to 24 inches) was performed weekly. Longer duration crops like peppers and sprouts typically had sample intervals between 1 and 3 weeks. For crops with established criteria for fresh sap nitrate levels, petioles were tested on same dates as soil samples. All crops with established nutrient adequacy ranges had leaves collected at the appropriate physiological stage for complete analyses. Irrigation well or surface water samples were collected, however no samples of district delivered water were analyzed.

Greenhouses and Nurseries – These businesses were all unique and required further alteration and customization to provide meaningful data and report to the clients. One time deep soil (to five feet) sampling was performed at two greenhouses, and irrigation runoff samples (nitrate and limited phosphorus analyses) were collected on a regular basis at two other nursery-type facilities. Phosphorus testing was not within the contract scope but was provided at the Contractor's expense at the request of the clients. No irrigation water samples were collected as all growers have routine testing programs.

Table 2. Summary of cropping systems evaluated

Grower Location	**Crop - Task**	**Irrigation Type**
Monterey		
	Walnuts	Fixed sprinkler
	Lemons	Micro sprinkler
	Leaf Lettuce	Sprinkler - Drip
	Head Lettuce	Sprinkler - Drip
	Head Lettuce	Sprinkler - Drip
	Head Lettuce	Sprinkler - Drip
	Head Lettuce	Sprinkler - Drip
	Head Lettuce	Sprinkler
	Head Lettuce	Sprinkler
	Head Lettuce	Sprinkler
	Head Lettuce	Sprinkler - Furrow
San Benito		
	Nursery Runoff	Sprinkler
	Peppers	Sprinkler
	Bok Choy	Sprinkler
	Walnuts	Sprinkler
	Strawberries	Sprinkler - Drip
	Fennel	Sprinkler
	Beets	Sprinkler
San Mateo		
	Brussels Sprouts	Sprinkler
	Brussels Sprouts	Sprinkler
	Leeks	Sprinkler
	Leaf Lettuce	Sprinkler
	Pumpkins	Sprinkler - Drip
	Daisies	Sprinkler
	Calla Lilies	Sprinkler
	Greenhouse Flowers	Sprinkler
	Greenhouse Flowers	Drip
	Tail water Residual soil nitrate	-na -
Santa Clara		
	Orchard Grass	Sprinkler
	Chili Peppers	Drip
	Chili Pepper	Drip
	Bell Peppers	Drip
	Celery – Baby Spinach	Sprinkler - Drip
	Field Flowers	Drip
	Persimmons	Sprinkler
	Plug Tray Runoff	Linear Move Sprinkler

RESULTS

Grower Meetings and Record Keeping

The Contractor held initial meetings with forty-one (41) potential grower clients, of which thirty-six (36) elected to receive NMP services. While intent and requirements of the NMP provided for three formal meetings with growers, in practice this only occurred in one instance and was with the grower collaborator on the DNDC projects. The late contract start compressed the available time period, size of geographic area, and location of many fields far from grower offices, shops, etc, as well as, conflicting schedules constrained the Contractor's ability to have routine short discussions with growers or ranch managers. All of the growers provided generous amounts of time for the initial and final meetings and generally all of these meetings were productive and informative.

However, it was clear at the final meetings that only a couple of growers ever referred to the technical materials provided. Much of this material concerned irrigation management. It was the Contractor's expectation that a review of pump and irrigation test reports would be made prior to the final meetings so that a formal discussion concerning scheduling could be well supported. Without these reports and data the Contractor was not able to completely fulfill the NMP task associated with irrigation scheduling.

Much emphasis was placed in the original RFP and during the pre-bid discussions on grower record keeping. The Contractor reviewed the Record form with each client, discussed what type of record systems were all ready used, and emphasized the importance of the record for the NMP field and for the grower business in general. The Contractor attempted to suggest that maintaining the Record form was an NMP requirement or at least obligation of the client in return for services.

As noted previously some growers were not asked to fill in a form. In one case a grower utilized CIMIS data routinely for irrigation scheduling, while in another case a grower had developed an irrigation scheduling approach following years of keeping soil moisture records using a portable TDR sensor tool. In a number of cases, limitations on water quantity or sprinkler pipe constrain a grower's flexibility to adjust schedules to a large degree. Finally, one grower used furrow irrigation for most of the cropping period, and without a meter (and lacking any pump data) it was impossible to determine the amount of applied water.

The Contractor only received five completed irrigation and fertilization forms from growers. Many forgot, despite reminders, and in two cases, the Contractor was able to get forms completed by reviewing calendar entries in the grower's office during the final meeting. A number of growers that participated in the NMP do not maintain any records of fertilizer and irrigation water application. This task required time and attention beyond the capabilities of the Contractor.

Soil Nitrate-N Monitoring

The majority of NMP field sampling activities were soil nitrate-N monitoring in the effective root zone of crops. In contrast to traditional pre-planting or post-harvest soil sampling for complete nutrient analysis, this monitoring approach is time and sample intensive. Ideally, in order to provide a different and more detailed interpretation of fertilization and irrigation management sampling should be concentrated around important crop production 'events' (e.g. pre-plant or sidedress fertilization) and periods when there is a higher potential for reduced fertilizer use efficiency by the crop.

Initially, the Contractor attempted to adhere more closely to the services 'template' outlined in the contract. However, after beginning work in a number of row crop fields and performing the intensive sampling required in the DNDC project, the Contractor determined that an expanded sampling regime that paired root and below root zone samples was providing a vastly improved interpretation of the interaction of N fertilization and irrigation management in many fields

Row Crops - As example, Figure 1 shows results from monitoring the effective rooting zone of a crop between the period prior to planting and post-harvest. One interpretation of this data might conclude that soil nitrate-N levels were never excessively high and that the declines in nitrate observed in August and late September into October were likely mostly due to crop uptake. In contrast the data in Figure 2 contrasts the same rooting zone data with that from soil largely below the root. The increases in soil nitrate-N found below the root zone in early August and mid- to late September now suggest that some leaching of fertilizer nitrate occurred during the crop period.

Figure 1. Example results from root zone nitrate-N monitoring

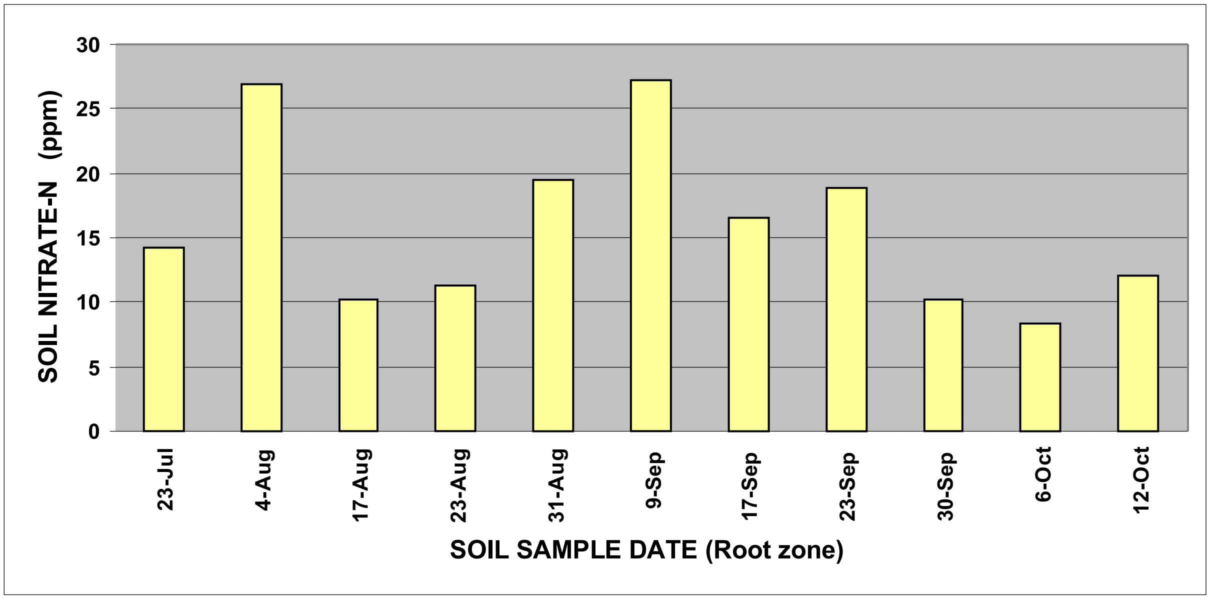
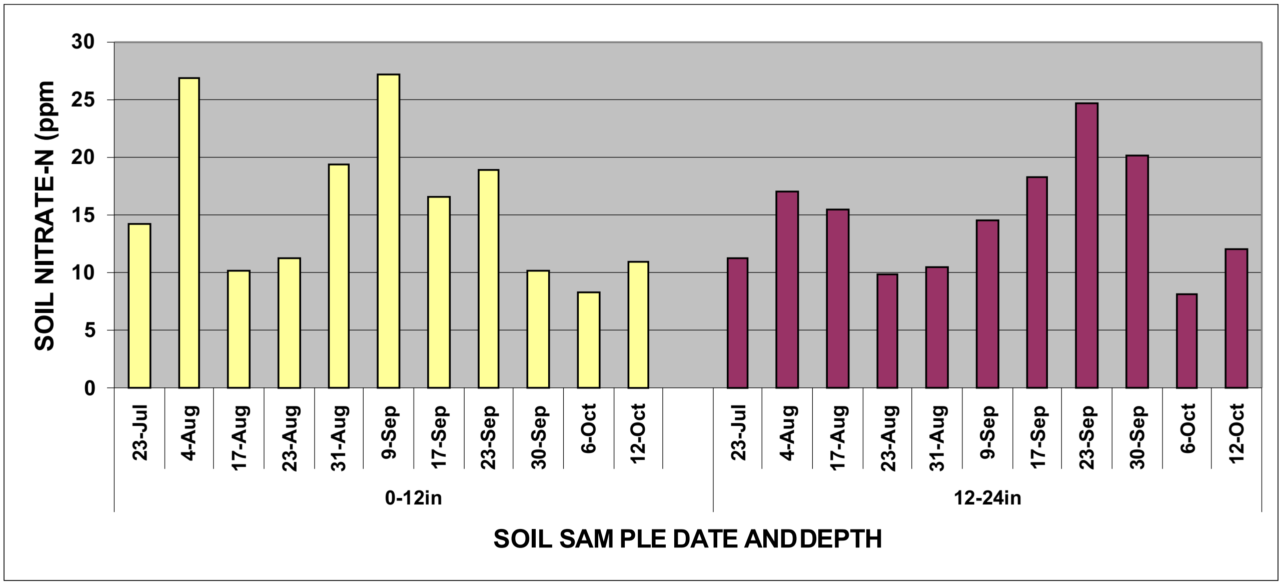


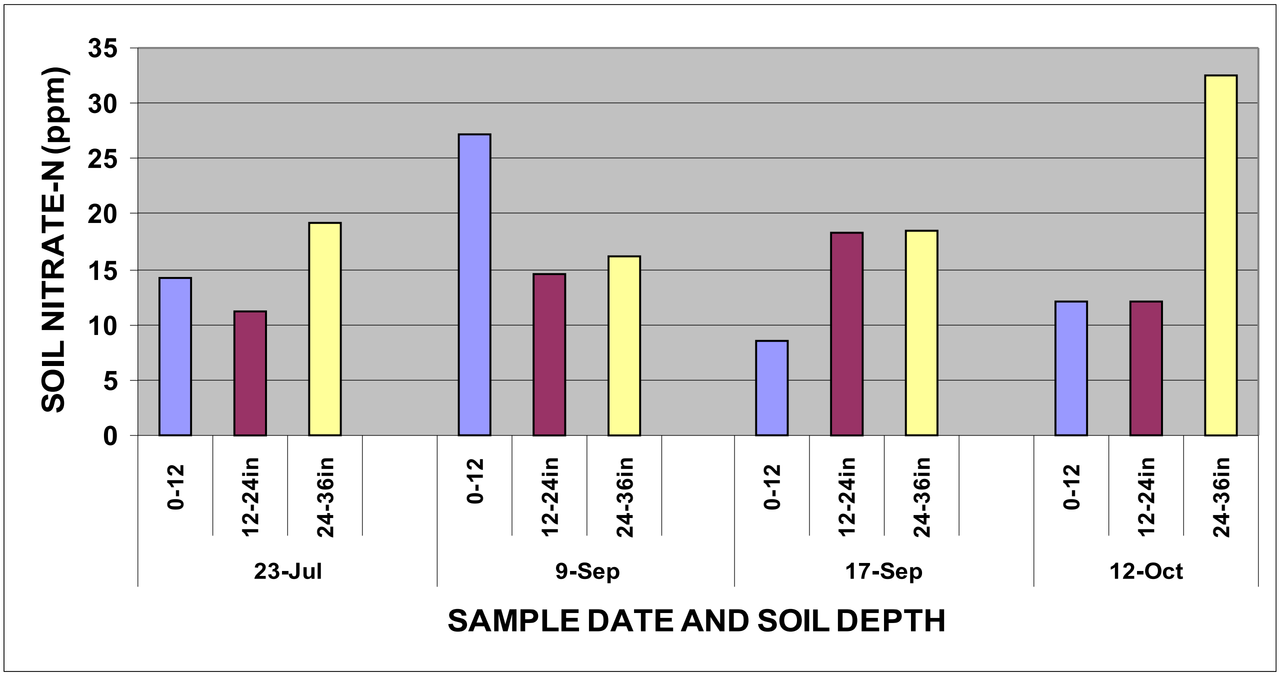
Figure 2. Comparison of example root zone and below root zone monitoring



Further suggestion of the potential for leaching during the cropping period is possible where the Contractor further adjusted the sampling protocol to include analysis of changes lower in the soil profile. Figure 3 shows data from the same field where increased sampling was done a few selected dates. The tan bars provide further suggestion of the potential for nitrate losses, likely the result of irrigation/fertigation scheduling.

However, it was not until the final meeting with this grower that the issue of irrigation water management could be integrated into the interpretation. This discussion provided some additional confidence concerning the interpretation of fertilization and probable excessive irrigation water percolation. While no irrigation records were provided, routine visual field observations by one manager suggested that the crop was over-irrigated.

Figure 4. Comparison of soil nitrate-N changes in the three foot deep soil profile

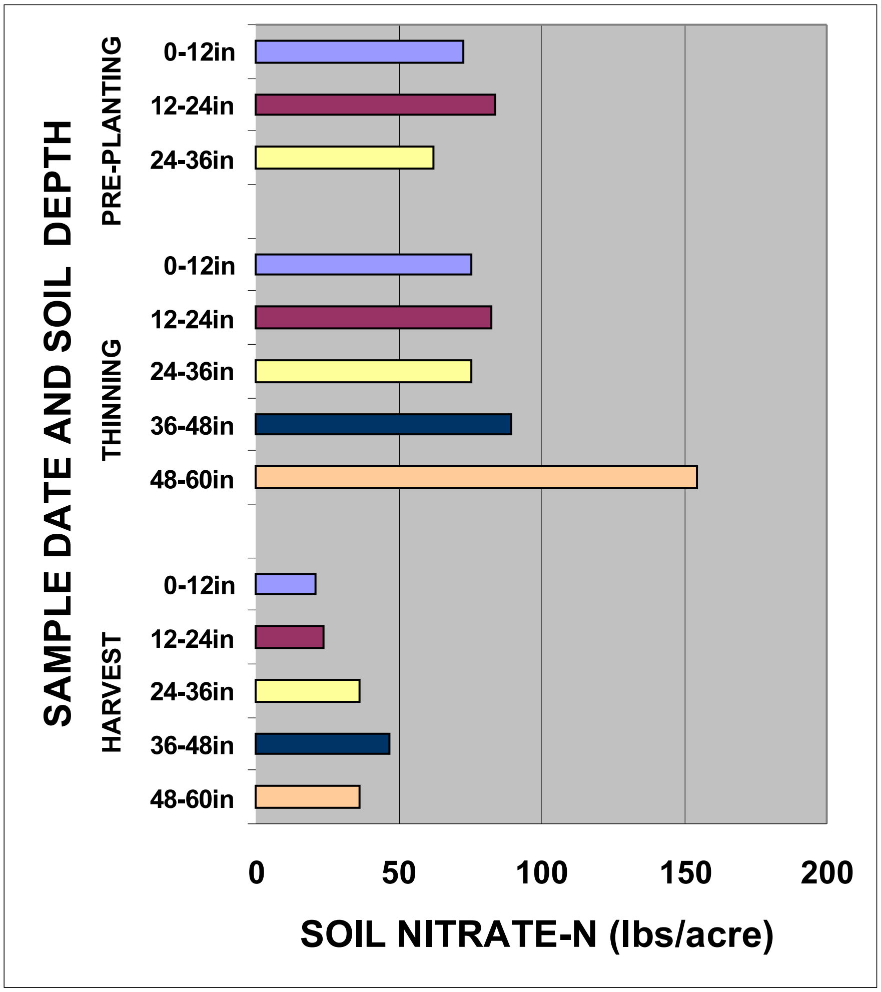


A cautionary reminder. Al of these data are collected, plotted, and interpreted from only single composite field samples. There remains a strong argument that without a sampling and data analysis protocol that includes sub-sampling for statistical analysis, it is impossible to state with confidence that any time-series differences actually occurred. Nonetheless this is the limitation that the Contractor must work around in order to provide any compelling interpretation and discussion with growers.

Further, these interpretations of leaching potential must also consider the likelihood or potential for reductions of nitrate in lower soil depths, by microbial denitrification. The Contractor was limited to determination of soil moisture content and visual assessment of the degree of moisture saturation in soil samples as a weak indicator of denitriification potential.

Deep soil profile comparison – On a number of fields with coarse (sandy) soil texture the Contractor adjusted the NMP template to increase the depth of pre-planting and post-harvest residual soil nitrate-N sampling. This was done to also increase the confidence of subsequent interpretation of fertilizer and irrigation interaction. Figure 5 demonstrates how quickly and dramatically irrigation can potentially mobilize residual soil nitrate. At pre-planting samples were collected to only the three foot depth. After further evaluation of the leaching risk on this field, thinning and post-harvest samples were collected to five feet. Between pre-planting and thinning of this crop, there was no apparent change. However in the following 45 days, it appears that there were large reductions in nitrate-N in the deeper soil, thus suggesting leaching during the crop.

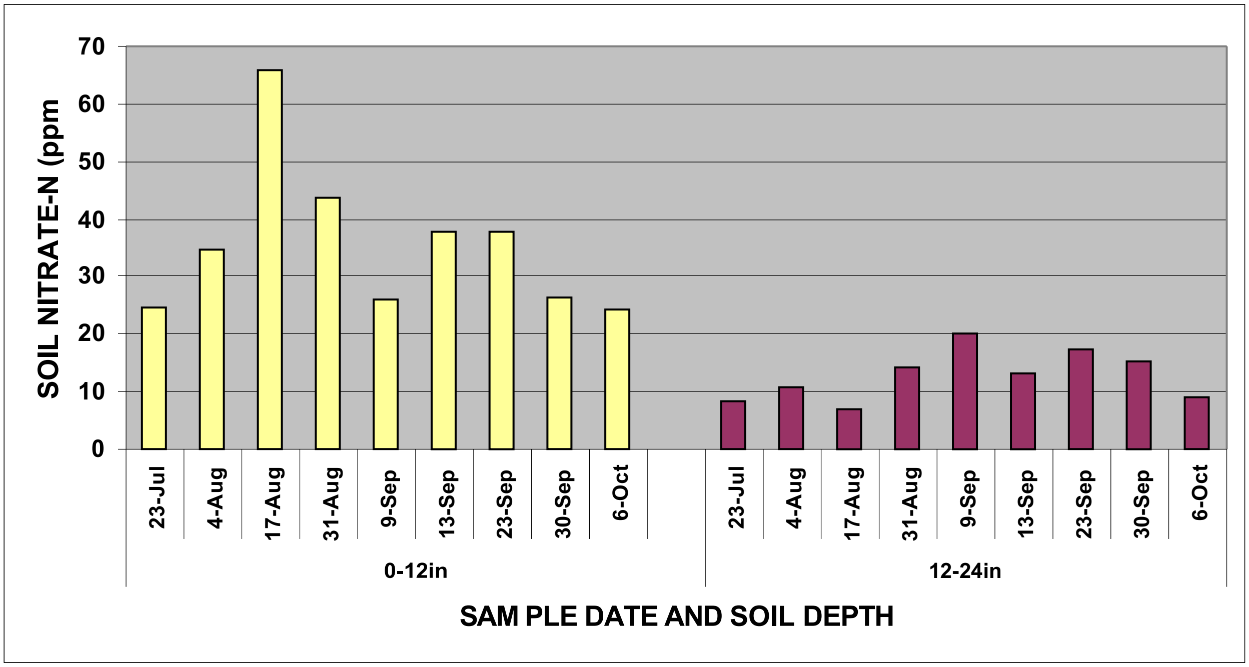
Figure 5. Estimates of soil nitrate N in the soil profile of a loamy sand field during cropping



As was noted in the previous example, without good information concerning irrigation scheduling the confidence in interpreting the changes observed is limited. In the case shown above, the grower provided irrigation records and following analysis by the Contractor it was found that this crop may have received 2.5 times more irrigation water than may have been required. Deep percolation of water and nitrate was inevitable. Conversely this grower applied a quite modest amount of N fertilizer.

As a final example and contrast Figure 6 shows data for a field on heavy texture soil with an inherently lower leaching risk. Despite an over application of fertilizer (consensus of grower and Contractor) there appears to have been less proportional movement below the rooting zone, particularly when considering the highest measured concentration of above 60 ppm early in crop establishment.

Figure 6. A second example of soil nitrate-N changes in and below the rooting zone

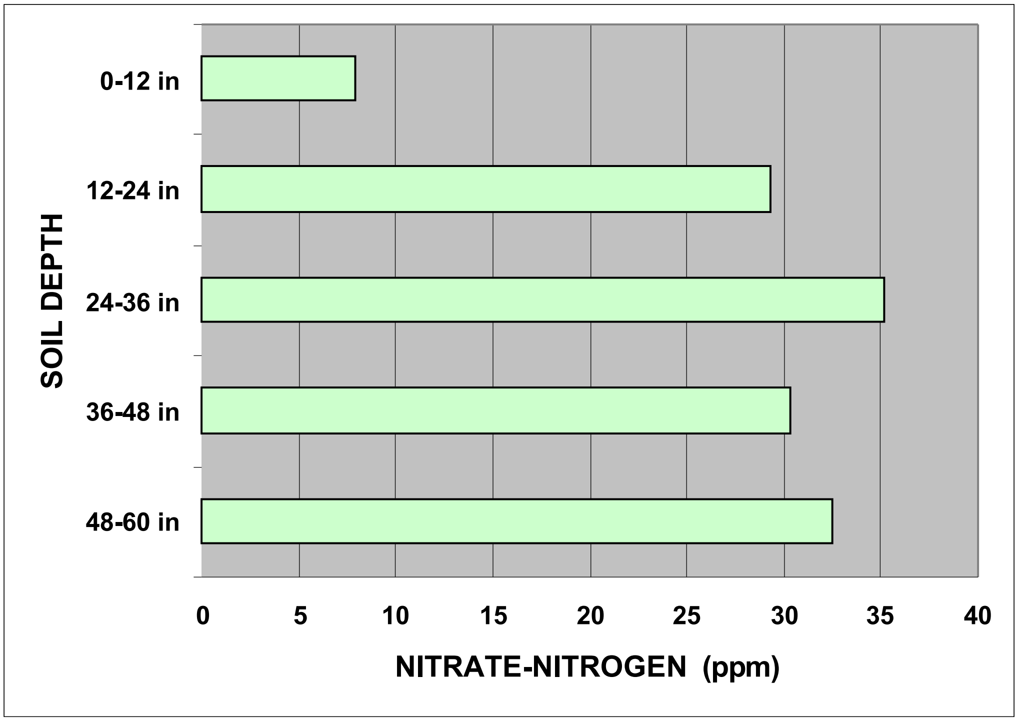


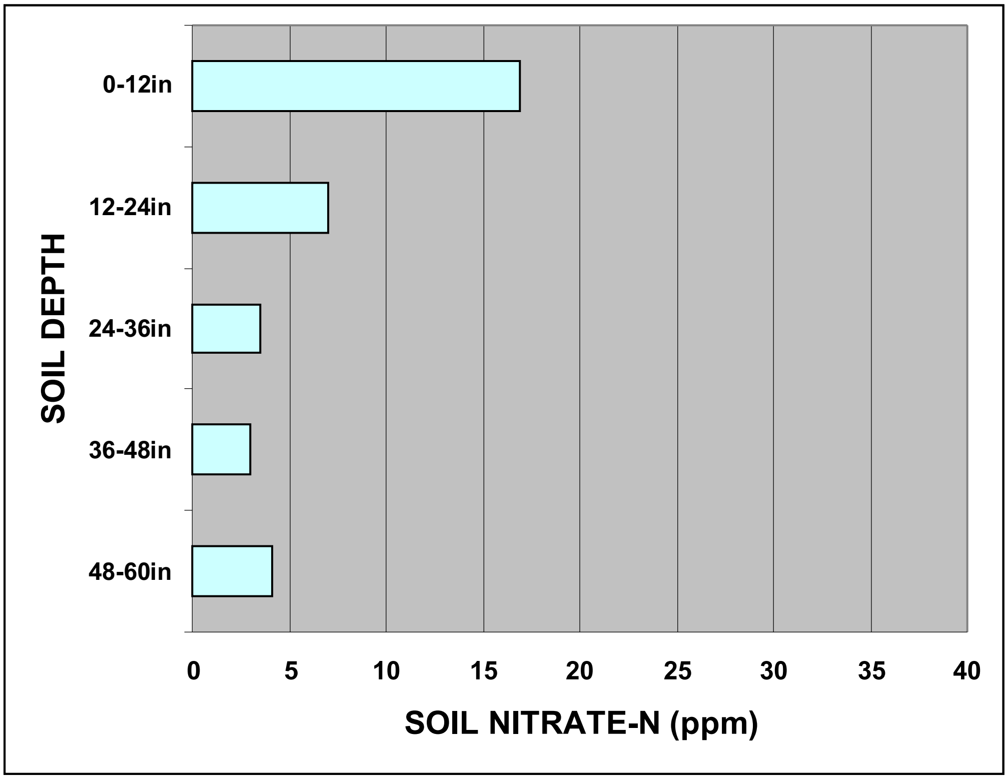
Again the interpretation of this data was enhanced during the final meeting with the grower. While the grower did not provide field specific irrigation records, details of typical irrigation schedules for that crop type indicate that the crop may have been slightly under-irrigated.

Other Production Systems- Two crop sites were sampled to the five foot soil depth in multiple areas to provide the clients with some indication and interpretation of how their fertigation and salinity management schedules affect residual and leaching of nitrate. While the crop types differed the soils, seasonal evapotranspiration, fertilizer materials and fixed injector ratios of fertilizer to water were similar.

Figure 7 shows soil nitrate-N to the five foot depth in one location that receives fertigation from overhead sprinklers. Figure 8 shows identical depth increments from a location that receives fertigation from surface drip. While leaching may occur in both locations, it appears that the magnitude may be quite different. The differences in the locations may be largely due to differences in irrigation scheduling practices of each grower. It less likely that drip irrigation technology alone is contributing to the apparent lower subsoil nitrate-N concentrations shown in Figure 8. This grower simply utilizes the technology to provide low volume applications of fertilizer and water at short time intervals dependent on weather and crop development stage. In contrast, the other grower irrigates/fustigates on a fixed schedule regardless of crop type and development stage.

Figures 7 and 8. Comparison of nitrate-N distribution in the five foot profile at two sites





Soil nitrate quick test kits – Only two nitrate quick test kits were distributed in 2005 and in both cases time availability or scheduling conflicts prevented the Contractor from providing training on the use and interpretation of this tool. While the existence, purpose, and use of quick testing was mentioned in most grower meetings, only a few were familiar with this tool. One of the recipients was more interested in using the test strips to evaluate nitrate levels in wells on a new ranch, than applying it for N sidedress decisions. Some expressed doubts about the reliability of 'self-testing'. However, the Contractor noted that there was an increased interest from some growers following the review of the NMP evaluation reports.

Soil Nitrate Monitoring Summary

Some of the example data (Figures 1, 2 and 6) illustrate some trends observed in the soil monitoring component. Many row crop fields had higher than necessary N levels in soil either prior to planting or during early crop establishment. This trend was more consistent in fields that were not planted until June, where apparently N release from incorporated crop residues and soil organic matter was significant. This trend was also found in double cropped fields where the NMP evaluation was performed on the second crop. Here residual fertilizer N and N release from crop residues is assumed to be the source. Under these conditions and where pre-plant N was also applied, N losses due to leaching are likely due to the small root system and crop N requirement. A number of row crop fields appeared to have adequate residual nitrate-N for the early establishment of a crop without additional N fertilizer.

Less frequent, but clearly documented with the evaluation protocols, were observations of consistent over-fertilization. This was not apparent (and expected) in any tree crop systems evaluated, but was observed in a few short and long season vegetable fields under both sprinkler and drip irrigation. Higher than optimal (> 10 ppm) post crop residual soil nitrate and potential early crop leaching losses were found more often in short- and medium-term crops, particularly where color is a market quality indicator. In long term cool and warm season crops, residual soil nitrate-N was often below 10 ppm. However, while this may be an indicator of low potential leaching losses during the winter rainy season, in-season leaching appeared to occur, particularly in long-term crops under drip irrigation.

N Fertilizer and Irrigation Water Interactions – Analysis of results from field work and reflection on discussions in the initial and final grower meetings, it is apparent that irrigation water management is perhaps a more consistently critical variable influencing in-season nitrate leaching potential in the region. This is particularly true in fields with soils of predominantly sandy texture in comparison to those with clay texture.

Most growers typically face many more operational variables that influence decisions concerning irrigation scheduling, as opposed to fertilization. Many farming operations from medium to large may not have contiguous production fields, therefore require either multiple irrigation crews managed by a single ranch manager or a single irrigation foreman must travel significant distances to operate and maintain systems The use of timers at well heads is not uniform. The knowledge and experience of irrigators varies, and occasionally a manager's instructions may be misunderstood. Constraints on water availability or labor may reduce operational flexibility and require fixed irrigation schedules.

These challenges are often discussed when growers and managers are asked about their basis or rules of thumb for scheduling irrigations. All acknowledge that weather and crop development stage are important factors, and most will indicate that decisions are best based on direct field observations of the crop and soil moisture status (most often judged by a feel or ribbon test). Growers and managers rely first on their experience, with reference to irrigation programs that have reliably resulted in a good yielding and quality crop. Only two growers in the 2005 NMP have experience with or use daily or weekly real time evapotranspiration data from weather stations.

Further, in a number of the fields where significant nitrate leaching potential during the crop may have occurred, the crop was being produced largely on drip irrigation/fertigation. Counter to the prevailing assumptions, there is some evidence that drip irrigation management can enhance deep percolation of water and nitrate. Discussions with growers and documentation of irrigation set duration and irrigation set intervals (when records were available) tended to support field data/observations regarding soil nitrate-N dynamics below the crop root zone. It is difficult for some growers or managers to determine when the crop root zone has been adequately replenished. A number of managers indicate that with surface drip, irrigation duration is largely determined by observing the time required for surface moisture to move laterally to the plant line. Few growers indicated that they are able to use frequent low volume (or short set duration) applications, often citing labor or other operational variables. However, it also appears that some assume that a low volume (or rate) delivery system should inherently reduce the risk of deep water and nitrate percolation.

The growers who had experience or familiarity with either CIMIS-based scheduling, had at one time utilized advanced soil moisture sensing, farmed in the fog zone close to the ocean, or had spent more time adjusting scheduling with drip all appear to be using more effective irrigation schedules that limit movement of nitrate.

Plant Tissue Analysis

Most grower clients received an analysis and interpretation of crop nutrition as assessed by a whole leaf analysis. In addition to this test, some crops also had regular evaluation of petiole nitrate (and for some crops potassium).

Fresh sap petiole – This is another rapid test method, that when properly ‘calibrated’ to a set of formally researched or evaluated adequacy guidelines can provide almost real time assessment of fertilizer and irrigation management impacts on crop N status. This test method is familiar to many pepper growers in the region, but few others. Following review of reports and cross-referencing of fresh sap nitrate data with traditional whole leaf analysis, a few more growers expressed interest in this test method in comparison those few curious about the soil nitrate quick test.

Generally petiole results largely supported soil nitrate-N monitoring revealing or confirming high or low soil nitrate availability during the course of crop development. Particularly in peppers, there was a weather related trend that revealed that during cool and overcast periods crop N demand decreased, while grower N applications (mostly weekly via drip) were not reduced resulting in either excessive uptake or increased leaching potential. Discussion with one grower confirmed that very high petiole nitrate levels late in the season (October) were due to excessive N applied to ‘push’ the crop to maturity.

Whole leaf – A number of growers were interested in the results of this test for nutrients other than nitrogen. Whole leaf analysis has a long history and a wealth of published adequacy data to draw interpretations. In most cases growers were interested to see if these results confirmed past or existing crop nutrition issues and/or to confirm that other soil fertility amendments were improving nutritional levels or balance. While total leaf N content and petiole nitrate analyses correlated very well, many growers were more interested in calcium, potassium, and zinc nutritional status. Indeed, issues related to calcium, copper, zinc, potassium, and phosphorus nutrition are common to the majority of grower enrollees regardless of geographic location

An effort was made to highlight phosphorus (P) status in crop tissue as a means to discuss current concerns and possible future regulatory actions related to phosphorus in runoff and sediment from farm fields. Only one leaf analysis revealed a possible crop deficiency that directly related to soil P status in a field recently converted from grass hay. In some other cases adequate, yet low P status could be linked to high soil pH (that reduces P availability), rather than low or deficient soil P. Generally P nutrition of crops and field observed is not a common problem impacting yield/quality.

The petiole and whole leaf analyses provided a more complete interpretation of the soil nitrate data. In particular the comparison evidently provided a more compelling indication to some growers of the potential value of petiole testing as a quick test method. As example, Figure 9 shows some petiole monitoring results, while Table 3 shows the results of the same crop's leaf analysis. The red line shown in Figure 9 is an average critical level for sap nitrate in this crop.

Figure 9. Comparison of petiole sap nitrate and soil nitrate-N in the root zone

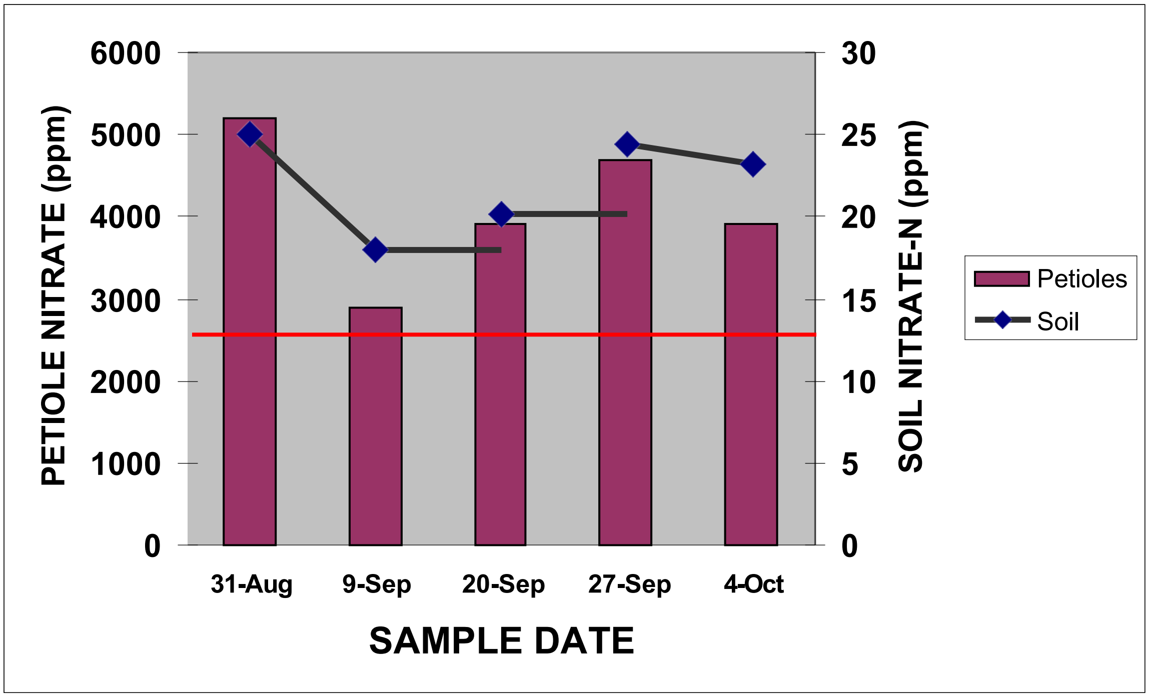


Table 3. Nutrient status determined from recently matured leaves on 27 September

Nutrient	Result	Range	Interpretation
Total N (%)	4.24	2.5 – 3.5	**HIGH**
Tot. P (%)	0.28	0.3 – 0.50	**SLIGHTLY LOW**
Tot. K (%)	7.20	4.0 – 6.0	**HIGH**
Tot. Ca (%)	1.27	1.4 – 2.0	**LOW**
Tot. Mg (%)	0.35	0.3 – 0.7	**OK**
Tot. Na (ppm)	1911	na	**OK**
Tot. Cu (ppm)	5.4	5.0 – 10	**OK**
Tot. Zn (ppm)	17.9	25 – 50	**LOW**
Tot. Fe(ppm)	277	50 – 150	**HIGH**
Tot. Mn (ppm)	65	20 – 40	**HIGH**
Tot. B (ppm)	26	15 – 30	**OK**
Tot. Mo (ppm)	0.51	na	
Cl (ppm)	14532	na	**OK**
Total Sulfur-S (%)	0.29	0.3 – 0.8	**SLIGHTLY LOW**

Complete Soil Analysis

All grower enrollees received a complete soil test, unless they indicated that they regularly sample and analyze samples, or had a current soil test report for the field. Again, many growers were interested in seeing if there was a link between soil nutrient status, general crop nutrition, and the amendments they utilize. Generally there were clear links between soil nutrient and leaf analyses. The most common concerns were about soil pH, calcium, potassium, and zinc status. For most fields evaluated across the entire region, growers are employing amendment programs to minimize the negative impacts of high magnesium. Growers close to the ocean utilize lime for reducing soil acidity and improving calcium supply, while most utilize gypsum for calcium and magnesium management. In the southern and eastern portions of the region a number of growers are experiencing increasing soil pH, often in relation to changing irrigation water quality. The Contractor also noted soils with higher than optimal sodium and chloride levels, most often related to well water quality, but also related to proximity to the ocean. Low boron levels are common, but crop deficiencies were less common, while excessive soil and crop boron are found in some of the eastern portion of the region.

With one exception, all fields evaluated had adequate to excessive levels of soil P. Fields in the northern portion of the region tended to have the highest soil concentrations of all areas. Generally most growers were/are not aware of the potential cumulative effect in soils due to annual P applications. Many growers were not aware of soil pH effects on soil P availability. Most applied P is in pre-plant fertilizer materials, while some drip fertigated crops receive small additional P from acid materials. All growers were informed of perceptions and concerns related to agricultural P loading in surface waters and all were informed of recent research in the Salinas Valley on lettuce response (or lack of response) to pre-plant P fertilizer.

Water Analysis

Irrigation – Concerns about irrigation water quality appear to be increasing, mostly due to overall salinity, bicarbonate, sodium, and chloride concentrations. A number of growers are concerned about negative impacts of bicarbonate and are or are considering low volume injection of acid materials to neutralize this constituent. A couple of growers noted that they have increased N fertilization in certain crops and fields to overcome yield and quality problems associated with poor well water quality.

These growers have not made any production responses to high nitrate concentrations in well water. There is a general awareness that high nitrate in well water can contribute to crop nutrition and potentially allow for lower N fertilizer applications. No grower explicitly adjusts there N fertilization programs for ranches or fields that are irrigated with high nitrate well water. The Contractor did note and discuss with growers that high N levels in crop petioles and leaves were consistently observed in fields irrigated with high nitrate water. However, it is still not possible to provide reliable guidelines for the potential availability of N in irrigation water that growers can implement as there is no adequate body of crop research to support this.

Grower clients that utilize surface water diversions and impounded water have few to no production constraints related to irrigation water quality. Nitrate-N levels are not detectable or at extremely low concentrations.

Runoff – A few growers desired to evaluate tailwater nitrate. In all cases these operations are located adjacent to surface water bodies, potentially discharge water in the irrigation season to ditches leading to surface waters, or receive drainage waters from adjacent farming operations. In all cases the drainage waters had the potential to contain residual N and P from injected fertilizers. These growers received reports that referenced their test results to the drinking water standard for nitrate and/or the RWQCB objective for P in surface waters. The results of this monitoring demonstrated that runoff water quality is directly related to fertigation through sprinklers. When and where fertigation occurred, nitrate-N in runoff consistently exceeded 10 ppm. There was no evidence of a cumulative effect, meaning runoff following water-only applications were typically below 10 ppm and at times even below the background nitrate concentration in well or surface irrigation water. Follow-up discussion with these growers included identification of alternative practices (e.g. time release fertilizers, vegetative treatments) to reduce potential nitrate loading.

Final Grower Reports

The formal reports attempted to integrate all field test results into a coherent assessment of the efficacy of N fertilization and irrigation management. The report also provides formal documentation of each grower's participation in the NMP and provided a reference for discussions in the final meetings. Report formats were varied slightly according to crop type or project work scope and ranged from 7 to 13 pages in length. Each included a project summary section, data plots and tables as shown in his report, along with reasonably brief text explanations. Additionally most grower reports included the below section, modified for their field and crop.

Nitrate Leaching Hazard Rating - Where appropriate the grower final report also included a brief description of a website designed to provide a user with a relative risk evaluation for specific field and crop system conditions. This was provided in order to inform the grower, but also to provide an additional reference comparison to results and conclusions from the field evaluation work. All row, field, and tree crop growers that had a complete field evaluation had a section similar to the below example.

> The UC Center for Water Resources at Riverside has developed and is promoting a simple model to provide growers and technical resource personnel with an evaluation and rating tool called the Nitrate Groundwater Pollution Hazard Index. It is an on-line website tool where a user enters basic information; soil series name, crop, irrigation system type, and tillage information (http://www.waterresources.ucr.edu). It computes a hazard index number indicating the relative nitrate leaching 'risk' for a field. The hazard index number can range from 5 through 80 with the risk of nitrate leaching increasing with higher numbers. Any field/crop system that rates higher than 20 is assumed to particularly problematic.
>
> The field evaluated is on the **Soquel loam** or equivalent soil series and with sprinkler irrigated pumpkins the hazard number is (=45) and for drip it is (=30). In reality any irrigation system in itself provides no guarantee of reduced or enhanced leaching as irrigation and fertigation scheduling can be even more important.
>
> Pumpkins - The amount of water applied during irrigation of crops with shallow roots must be carefully monitored. Otherwise soluble nitrate may be leached beneath the crops rooting zone prior to the time required for the crop to utilize the applied N for plant growth. Significant amounts of N are taken up during the growth of pumpkins. This leaves little behind in the soil to be leached. Some of this N accumulates in the marketable portion of the plant structure, but some is also left behind on the surface of the soil after harvest. This N left behind in the plant tissues can be mineralized and then leached during the rainy season.

The Contractor brought an electronic copy of the report to each grower meeting and reviewed the report results and interpretations page-by-page. Many noted that is was most helpful to have a printed report and the in-person review. In all cases the growers or managers indicated that there was value and reasonable rigor in the field methods. For most, these evaluations provided new information. Judging by the type and detail of some questions and discussions most found value in the NMP evaluation and, if available, most would continue with similar evaluation programs in the future.

SUMMARY OF OBSERVATIONS

As noted occasionally in this report, the Contractor made some limited analysis of trends based on qualitative and quantitative observations of nutrient and irrigation management practices. The NMP has not performed enough evaluations with enough growers to have high legitimate confidence in these observations. It should also be noted that this is a self-selected population that may not be representative of the average or ‘extremes’ of practices and management in the region.

- The apparent efficacy of irrigation management and scheduling varies often leading to under- and over-irrigation in many fields. Use of and even familiarity with CIMIS weather data and/or computer-based irrigation scheduling is rare. Few growers can describe irrigation applications on an inches per acre basis or can estimate daily crop water use or requirements
- All growers are not fully exploiting the potential benefits of drip irrigation technologies and, in some cases, may increase the leaching potential with less than optimal scheduling
- Irrigation management and early crop N fertilization may be the most consistent variables influencing nitrate leaching during cropping
- Residual soil nitrate-N resulting from early season crop production or following early season plowdown of cover crop or crop residues may often reduce or eliminate the need for pre-plant N in a mid-season planting
- Winter season leaching potential due to residual soil nitrate increases when the last crop residue plowdown occurs in late summer-early fall when soil temperature are high enough to allow rapid decomposition and subsequent nitrification
- Growers do not have experience or guidelines to adjust/reduce N fertilization when irrigation water sources contain agronomically significant nitrate-N concentrations
- Certified organic production with low N materials predominantly of organic and ammonium-N content generally have low nitrate-N levels in the soil profile regardless of crop type, irrigation methods or scheduling
- Many smaller growers do not utilize regular soil or tissue testing to evaluate fertilization and amendment practices
- Soil P levels tend to be at adequate to excessive levels in most soils, yet many growers lack confidence to eliminate P fertilization on any crop
- Market quality standards continue to pressure some growers to increase N fertilization solely for color
- The increase in fertilizer costs during 2005 may increase incentives for many growers to be interested in improving the efficacy of N management

RECOMMENDATIONS

The Contractor was asked to provide a review of the 2005 Regional Mobile Ag Lab Program and recommendations on the scope of services, program implementation and opportunities to improve the delivery of NMP services in 2006. This section provides an analysis of current services, field methods and test parameters, followed by program delivery.

Services and Methods

- The present scope of soil nitrate, complete soil and tissue sampling, and irrigation water analysis provides a concise agronomic interpretation that is unique for most row crop growers.
- Expand/modify NMP service options for tree crop and greenhouse growers. For some tree crop and greenhouse growers, most of the services offered (one time soil and leaf test) are less valuable (redundant?) as these are often received regularly from a privately contracted vendor. All tree crop growers were very interested in soil moisture monitoring equipment to improve irrigation management.
- The template of NMP services must be sufficiently flexible to provide meaningful information to non-row crop growers, including greenhouses or nurseries that may produce in soil less container media and/or plug trays both indoor and outdoor.
- Consider expanding any runoff testing to include phosphorus. Current water quality protection concerns (falling within the concept of nutrient management) include impairments due to nitrate; phosphorus, and salts. The current service scope does not specifically provide for routine testing related to dissolved phosphorus in water. A few 2005 participants inquired if such testing was possible.
- Collect early season or pre-plant soil samples. With a late program start, early season pre-plant soil testing was not possible in 2005. A number of growers expected that soil test results would be provided in the spring or in time to make pre-plant fertilizer or amendment decisions. In fields where the evaluation is performed on the second crop rotation (e.g. head lettuce) or where crop residues were incorporated months ahead of planting a pre-plant there may be more than adequate soil N to establish the crop. Pre-plant sampling may have immediate and tangible value to some growers.
- Routinely evaluate soil nitrate in and below the effective root zone of annual row crops. The Contractor found that modifying the routine soil monitoring template to include a concurrent sample of the effective root zone and below often provided more interpretive value concerning nitrate movement than comparisons of deep soil profile samples prior to and following harvest.
- Sampling and comparison of residual soil nitrate in the deeper soil profile (pre-crop ad post-harvest may be more informative/valuable in shorter-term crops where less total water is applied during the crop. Longer-term crops receiving higher volumes of water can mobilize nitrate to greater depths than three feet, particularly on soils prone to faster/deeper percolation.
- Certified organic production practices may need to include evaluation of soil ammonium-N levels. Routine monitoring of soil nitrate may have less value and applicability in certified organic production where growers do not use nitrate-containing fertilizers but apply low N concentration organic-based fertilizers with high ammonium-N contents and potentially lower nitrification rates in soil. None of the certified organic fields evaluated appeared to have significant nitrate leaching potentials, however this does not imply that over-fertilization is not possible

- Despite the inevitable poor return percentage, continue to request irrigation records, as when were available, greatly improved the analysis by the Contractor and discussion with growers. All growers agreed that the Record Keeping form was simple and understandable. Some mechanism to further motivate and ensure that growers maintain (and return) irrigation and fertilizer records should be implemented. Currently there is no incentive to the NMP Contractor to repeatedly remind and cajole grower participants
- A standard irrigation system test summary page or descriptive handout should be provided to growers at either the initial meeting or in the mailed report. Many growers noted that they could not understand or found little value in the irrigation system reports. The NMP Contractor reviewed a number of client reports in order to point out what and where the important findings were. Many growers apparently have no reference for a standard 'good or excellent' distribution uniformity (DU) estimate.
- Some direct follow-up with growers concerning pump and irrigation system test results may be necessary. A number of growers noted that they expected a follow-up meeting with the pump and irrigation contractor. The NMP Contractor initially advised each grower that they or a management-level representative should be present during the testing to get information directly from the evaluator. However this is not always possible or practical in the busiest times of the season
- More outreach and education regarding the factors influencing P availability, when and where pre-plant P applications are effective, and the current water quality concerns and the mechanisms for P loading in surface waters

Program Delivery

- The initial recruitment/contact list system was confusing and led to a few misunderstandings by the Contractor and growers. The Contractor would have preferred to have received a weekly 'Add New Contacts' list to incorporate into an existing data base.
- More program and offered services descriptions should be provided initially to potential enrollees in order to facilitate their choice of services (Nutrient, Pump, Irrigation System)
- Grower recruitment should be ended by mid-March to provide more flexibility and choice to grower clients. Obviously the delivery of NMP services was negatively impacted by the late start date and other administrative delays related to formal project start-up. In a few cases the NMP Contractor started projects in fields with established crops and missed some important sample points. A few growers expressed mild disappointment that work was not done in the crop or field of their preference.
- The NMP Contractor should continue to work directly with Farm Bureau Coordinators to schedule and participate in grower meetings, as well as, receiving assistance with any problems in grower contact, field access, other scheduling/communication matters
- The NMP Contractor should be informed of other Regional Program outreach events in order to better present all Program elements to growers and to encourage attendance/participation by these more motivated and proactive businesses
- The NMP Contractor should make a minimum of two presentations per year to the RPAC. The Scope of Work implied that the Contractor would at times be asked to attend RPAC meetings. The Contractor was never formally invited to make a presentation to the work group in 2005
- The NMP would benefit from better integration with the pump and irrigation system testing program. The NMP Contractor should have immediate access to pump and irrigation report results in order to best present and discuss irrigation scheduling with growers

APPENDIX I

REGIONAL MOBILE AG LAB NUTRIENT-IRRIGATION PROGRAM

FERTILIZATION AND IRRIGATION RECORD - 2005

BLOCK/FIELD____________________ **CROP AND PLANT DATE ________________**

IRRIGATION TYPE______________- ____________________
RATED OR MEASURED FLOW RATE*____________________ **MEASURED DU** ______________**

* Either flow rate (gpm or gph) for single head or emitter -OR- inches per hour for system
** Distribution Uniformity

NITROGEN FERTILIZERS (e.g. 17-17-17, 20-0-0-5, CAN-17)

APPLICATION METHODS (e.g. sidedress, topdress, sprinkler injection, drip fertigation)

IRRIGATION				**NITROGEN FERTILIZATION**			
Date	Type	Hours		Date	Type	Method	lbs or gal/acre

ADDITIONAL NOTES OR INFORMATION:

,.J M Lord *agricultural* • *COIISll/ting*
incorporated *scientists* *eng;neers*

engineering & agronomy studies • irrigation & drainage designs • soil & water evaluations • laboratory services

April 24, 2007

Santa Clara Valley Water District
Attention: Accounts Payable
P OBox20670
San Jose, California 95160-0670

REFERENCE: Invoice# 11893, Purchase Order GEN-793

To Whom It May Concern:

The attached invoice number 11893 is submitted per your instructions. The buyer name is Dannette Lewis. The contact name is Greg Meamber.

This billing is for the **2006 Program Summary Report** for the **REGIONAL** program only.

We appreciate the opportunity to be of service to the District.

Sincerely,

(559) 268-9755

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REGIONAL PROGRAM

Quantity	Item	Description	Unit Price	Extension
I	I	Item 8 Annual Report Grower: MOO! March ?007	$3200.00	$3200.00
Attachment for each item includes: Completed 2006 Program Summary Report 1 attachment included			Page Subtotal **TOTAL:**	$3,200.00 **$3,200.00**

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2006 PROGRAM SUMMARY REPORT

IN-FIELD NUTRIENT MANAGEMENT ASSESSMENT ASSISTANCE PROGRAM

April2007

SANTA CLARA VALLEY WATER DISTRICT

Prepared By:

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EXECUTIVE SUMMARY

In 2006, 110 growers participated in the SCVWD In-Field Nutrient Management Assessment Assistance Program. This included growers from San Mateo (SM), Santa Clara (SC), Santa Cruz (SZ), San Benito (SB), and Monterey (MO) Counties. Twenty-eight crops were represented in the program. Water and nitrogen usage was monitored through out the crop season with the intent to identify ways to prevent nutrients from moving below the crop's root zone and potentially into the groundwater.

Growers were asked to record nitrogen and water applications throughout the season. In addition, soil, tissue and water samples were tested for nutrient content. The combination of the sampling and record keeping provided growers with a comprehensive view of nutrient tracking from application to harvest.

At the end of the year, the records and sample results were reviewed and findings discussed with the each grower. Overall, growers were only applying about 58% of the water needed to meet crop ETo requirements. Thus, water usage was conservative.

Nitrogen usage was not as conservative. Almost a third of all growers had higher concentrations of nitrogen in the soil at the end of the season than at the start. Several crops were consistently more likely to have higher post season nitrogen levels. Also, variability in the crops, production goals, and production systems had an impact on how nitrogen was used at the site. The scope of the project did not allow for addressing all issues related to nutrient management; however, the project did identify areas where growers can potentially reduce production costs and groundwater quality impacts.

The majority of the growers were interested in the information provided by the program and indicated that it was beneficial. The Program introduced the use of soil and tissue samples to track nitrogen which gave growers a better understanding of the impact of their management strategies on production costs and groundwater impacts.

INTRODUCTION

The objective of the In-field Nutrient Management Assessment Assistance Program was to assist growers in the Santa Clara Valley Water District (District) located in San Mateo (SM), Santa Clara (SC), Santa Cruz (SZ), San Benito (SB), and Monterey (MO) Counties in reducing nitrogen loading into the groundwater through improved water and fertilizer use.

The project was designed to be an educational program for growers. The primary goal was to inform growers how to manage water and nutrient applications for a crop to reduce or eliminate leaching of applied nutrients into the groundwater aquifer. Each grower was provided with information as how to track nutrient application and usage through the use of various field samples and record keeping. Water management was also addressed as it related to both crop water needs and nutrient movement through the soil profile.

The services provided by JMLord, Inc. included technical assistance by collecting, analyzing and reporting soil, plant, and water-based fertility data. Specifically, the project tasks included the following:

1. Meeting with Grower explaining the program
2. Water Sample
3. Composite Soil Sample, Top foot
4. Tissue Sample - Complete Leaf
5. Set of Tissue Samples -Petiole (up to 12 samples per year)
6. Soil Nitrate Profile, first & second foot.
7. Annual Report

This included the presentation of data and options related to nutrient management to the growers as well as training on record keeping regimens and monitoring approaches. An annual end of season report was completed, which discussed the effectiveness of the project to reduce nitrogen loading to groundwater through improve management of water and nutrient resources.

The District retained JMLord, Inc. (JML), to provide these services to growers. The program was fully funded by the District with no direct cost to the grower. To provide privacy for the grower, each grower was assigned a unique reference identifier. All laboratory reports, analysis and references to the grower contained this reference number for identification purposes.

I SUMMARY OF WORK PERFORMED

The following services were performed for each grower involved in the program:

1. An initial meeting was held with each grower to explain the program and collect information pertinent to the program.

2. A water sample from the grower's water supply was collected during the crop season from a location upstream of any fertilizer or chemical injection. The sample was processed for agricultural suitability, including salinity, toxicities, and nitrates. The laboratory results and analysis were delivered to the grower and the findings were discussed.

3. A composite soil sample was collected prior to the primary growth season. The sample was processed for agricultural suitability, including salinity, toxicities, nitrates, phosphates and potassium. The laboratory analysis and recommendations were delivered to the grower and the findings were discussed.

4. A leaf tissue sample was taken during the crop season. The sample was processed for salinity, toxicities, and both macro and micro-nutrients. The laboratory analysis and recommendations were delivered to the grower and the findings were discussed.

5. Up to twelve petiole tissue samples were taken during the crop season. The samples were processed for nitrogen, phosphorous, and potassium. The laboratory analysis and recommendations were mailed to the grower.

6. A post-harvest composite soil nitrate profile was collected. The samples were processed for nitrate levels only. The laboratory analysis and report were mailed to the grower. The findings were discussed in person during the final grower meetings.

7. A final report to the grower was generated to summarize the work performed. This included the sample results and recommendations, the options provided and implemented, and an evaluation of the effectiveness of the program in meeting the objective of reducing nitrogen loading to water resources. A meeting was held to discuss the findings for the season.

II PROJECT SUMMARY

1. Cropping Systems

Within the five counties, there were 28 different crop types evaluated in the program. These can be divided into seven distinct crop groups: greenhouse/ nursery, hay/pasture, lettuce, permanent, row, turf (only one grower), and vegetable. Primary crops within each division are listed below. The number of growers, by county, within each crop grouping is summarized in Table 1.

Greenhouse/Nursery:
Flowers -Mums, Yarrow, Aster, Carnations, Petunias, etc.
Trees - Maple, Redwood, Citrus
Vegetables (transplants)- Celery, Peppers, Tomatoes, etc.

Hay/Pasture:
Alfalfa Hay and Fescue Pasture

Lettuce:
Head Lettuce, Romaine Lettuce, Green Leaf Lettuce

Permanent:
Cherries, Plums, Walnuts, Christmas Trees, Wine Grapes, Raspberries, etc.

Row Crop:
Com

Turf Crop:
Turf Grass

Vegetable:
Beans, Broccoli, Brussels Sprouts, Peppers, Strawberries, etc.

Table 1: Crop Summary by County

County	No. Farms						
	Greenhouse/ Nursery	Hay/Pasture	Lettuce	Permanent	Row	Turf	Vegetable
SC	8	4	4	29	1	1	9
SM	2	-	-	3	1		7
SZ	1	-	1	4			6
MO	6	-	8	5			2
SB	2	-	2	2			2
Total	19	4	15	43	2	1	26

2. Water Evaluation

As part of the program, growers were asked to record irrigation events throughout the crop season. Only a portion of the growers were able to provide irrigation information for the crop season. Of these, 17 crop types were represented. For each grower's crop type and growth season, an estimate of the ET (evapotranspiration) requirement for each field was calculated based on actual measured 2006 ETo values from a CIMIS weather station located within each county. This reference number was then compared to the total depth applied, based on information provided by the grower.

As shown in Figure 1, on a county by county basis, growers did not apply more water to crops then required by measured ETo values.

Figure 1: Water Usage **By County**

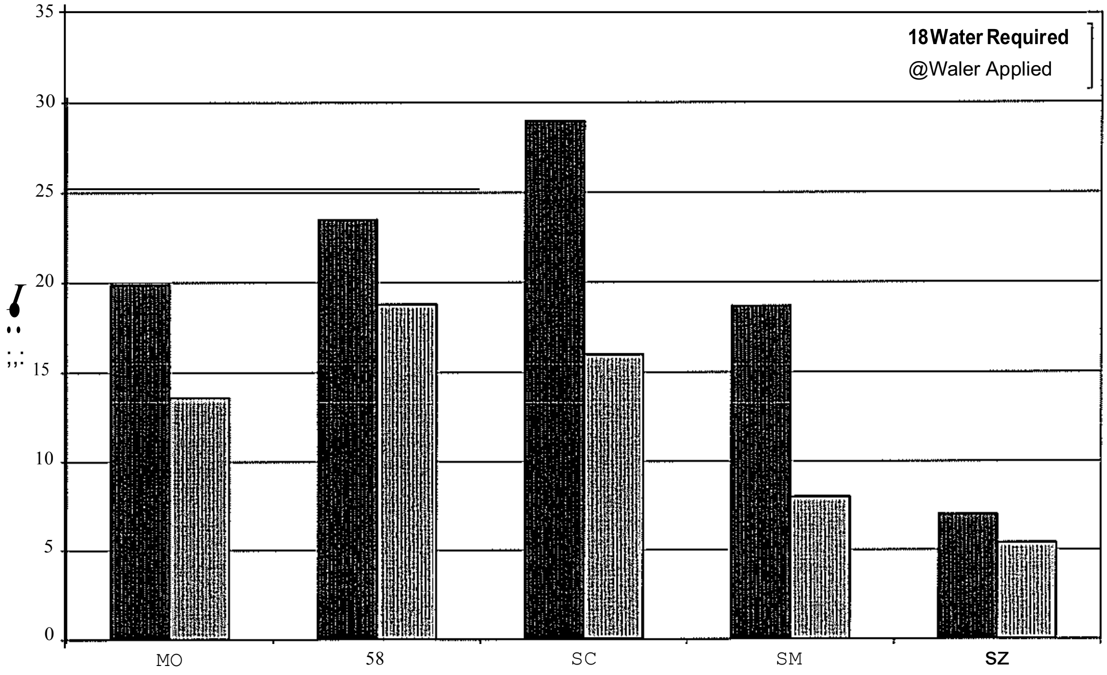
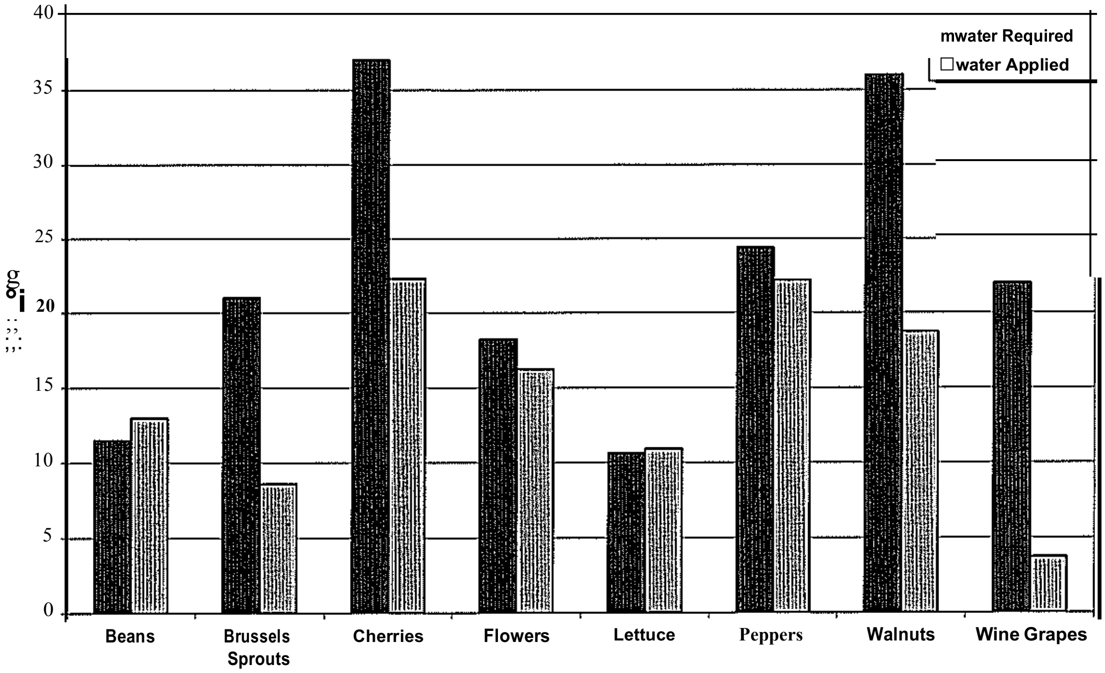


Figure 2 illustrates water usage by crop. When reviewing by ·crop type, on average, bean and lettuce crops were the only crops where more than the crop water requirement was applied, receiving slightly more than the recommended amount of water.

Figure 2: Water Usage By Crop



Overall, the growers applied, on average, 58% of the recommended depth of water to meet ETo crop requirements. Rainfall probably provided the majority of the remaining water needed for the crop season, although it was not considered in the crop water use. Based on this data, it is assumed that, in general, growers in the region are not over applying water to their crops.

3. Nitrogen Evaluation

It has been well established that nitrogen is a key requirement of crops to maximize yields. However, it is also known that there is an upper limit to the return of adding nitrogen and increasing yields. Addition of nitrogen applied beyond this upper limit can leave the residual nitrogen susceptible to leaching into groundwater. Also, excess application of nutrients is an additional expense to the farming operation (decreasing the profitability of the operation).

Each grower in the program was provided an estimate of the annual nitrogen requirement for each crop based on typical recommended values. This recommended value was then compared to the total applied nitrogen, based on information provided by the grower.

The nitrogen content of a clean irrigation water sample and a pre-season soil sample was determined for all farms in the program. For 93 growers, post-season nitrate profile soil samples (0-1 ft & 1-2 ft) were taken and tested for nitrogen content. Most of those not sampled after the season had short season crops which were harvested or removed from the site before any additional sampling could occur.

By County:

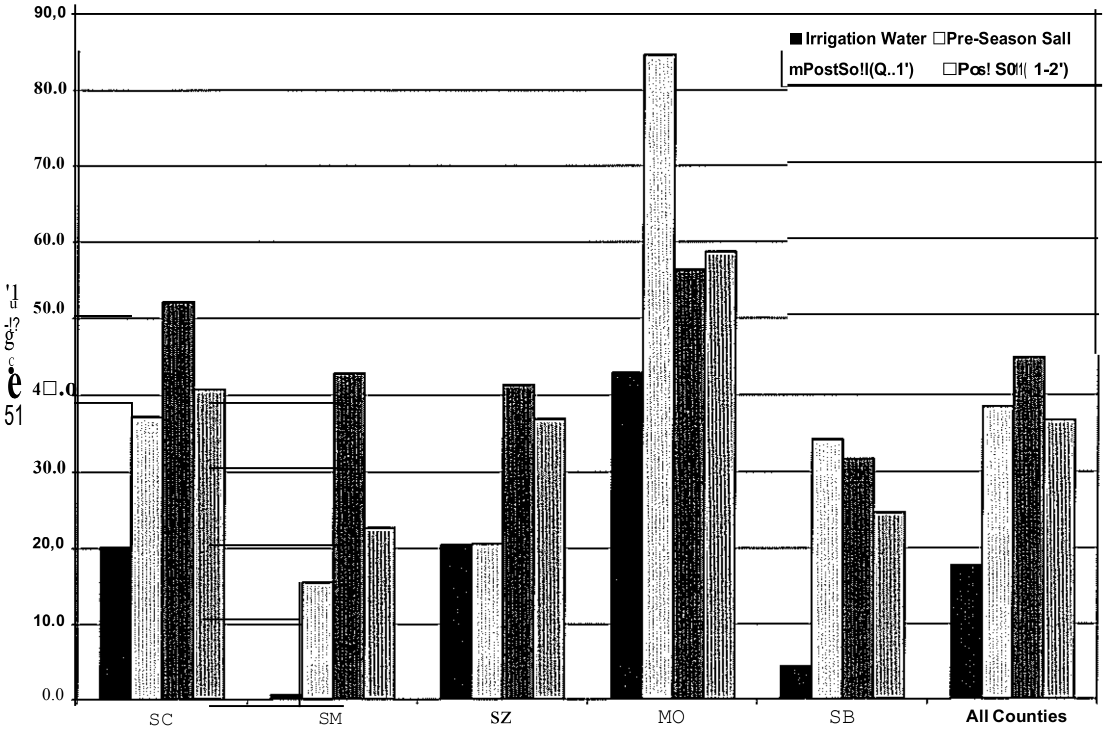
For all counties, nitrogen level in the soil at the start of the season averaged 38.5 lbs/ac-ft as shown in Table 2 and Figure 3. For irrigation water, the average nitrogen level was 17.7 lbs/ac-ft. In the post season, nitrogen remaining in the soil at 0-1 ft and 1-2 ft was 44.9 lbs/ac-ft and 36.7 lbs/ac-ft, respectively. Of those with post season sampling, 75% had higher nitrogen levels in the first foot of soil at the end of the season than at the start. Of these growers, nearly 50% had 25 lbs/ac-ft or more of nitrogen remaining in the soil than in the pre-season sample.

When reviewing the nitrate profile results on a county by county basis without regard to acreage, a third of the 93 growers had more nitrogen in the second foot than the first foot of the profile. This indicates the possible movement of nitrogen below the root zone, especially in shallow rooted crops. Seventeen growers had a first foot nitrogen level that was higher than the pre-season soil sample and a second foot level that was higher than the first. These growers were more likely to loose nitrogen below the root zone. Santa Clara and Monterey counties had the most farms in these categories. Monterey County also had the most nitrogen in the soil and water at the start of the program than any other county.

Table 2: Nitrogen Summary by County

County	# Farms	Pre-Season Soil	Irriqation Water	Soil Profile	
		N (lb/ac-ft}	N (lb/ac-ft)	0-1' (lb/ac-ft)	1-2' (lb/ac-ftl
MO	21	84.7	42.9	56.3	58.7
SB	8	34.3	4.4	31.7	24.7
SC	56	37.2	20.2	52.1	40.8
SM	13	15.5	0.6	42.8	22.7
SZ	12	20.6	20.5	41.3	36.9
All Counties	110	38.5	17.7	44.9	36.7

Figure 3: Nitrogen Levels by County



By Crop Group:

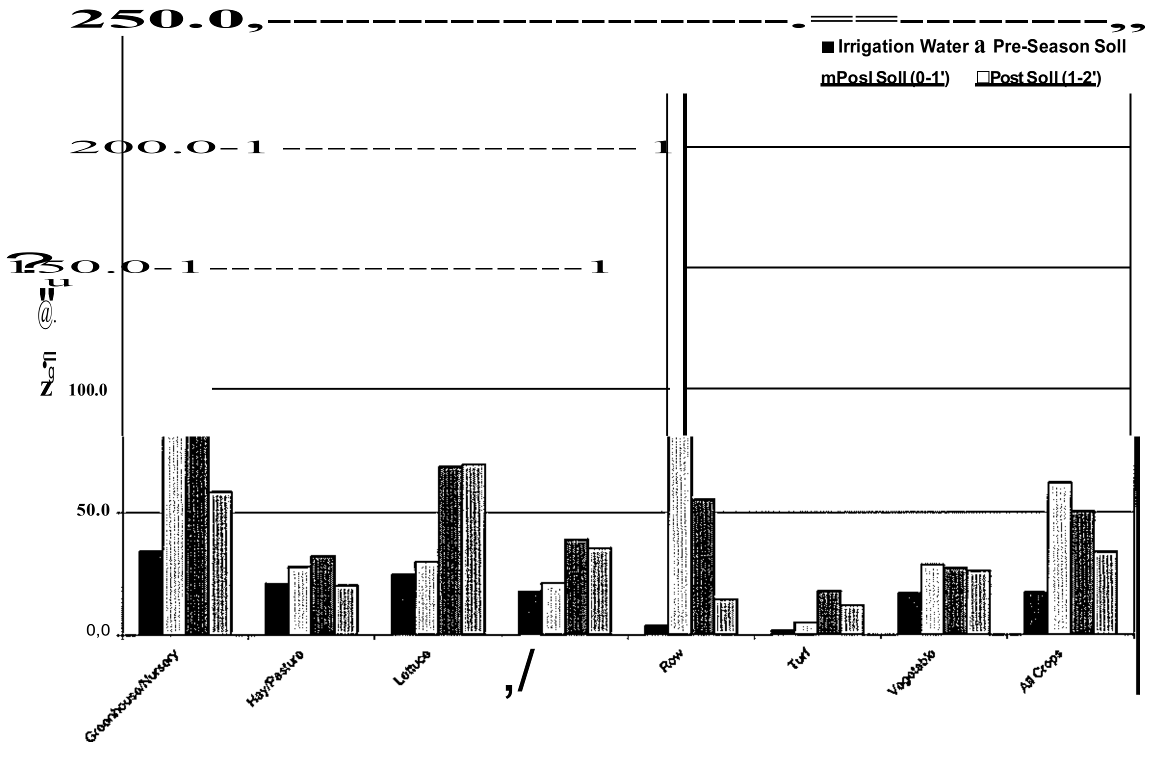
For all crop groups, nitrogen level in the soil at the start of the season averaged 62.2 lbs/ac-ft as shown in Table 3 and Figure 4. For irrigation water, the average nitrogen level was 17.2 lbs/ac-ft. In the post season, nitrogen remaining in the soil at 0-1 ft and 1-2 ft were 50.3 lbs/ac-ft and 33.7 lbs/ac-ft, respectively. In general, there was less nitrogen in the second foot than the first foot of the post-season soil sample.

The lettuce crop had the largest negative difference between the pre and post soil samples with an increase of nearly 40 lbs/ac-ft. Also, the second foot of the post-season soil sample was nearly the same as the first. This indicates that nitrogen is most likely moving through the soil profile and below the root zone.

Table 3: Nitrogen Summary by Crop Group

Crop Group	# Farms	**Pre-Season Soil**	Irrigation **Water**	Soil Profile	
		N llb/ac-ftl	**N** llb/ac-ftl	0-1' llb/ac-ftl	**1-2'** (lb/ac-ftl
Greenhouse/Nursery	19	101.6	34.3	112.0	58.5
J::l?!)(/Pasture	4	27.8	21.0	32.2	20.2
Lettuce	15	29.7	24.7	68.7	69.7
Permanent	43	21.1	17.7	38.8	35.3
Row	2	221.5	4.0	55.2	14.4
Turf	1	5.0	2.0	18.0	12.0
Vegetable	26	28.5	17.0	27.2	26.0
All Crops	110	62.2	17.2	50.3	33.7

Figure 4: Nitrogen Levels by Crop Group



Fertilizer Applications:

As part of the program, growers were asked to record nitrogen fertilizer application events and rates. Approximately two thirds of the growers were able to provide this information at the end of the crop season. For these growers, a complete nitrogen balance could be completed. The reference application rates were based on the average crop yield for the area. Based on this analysis, half of these growers applied excess nitrogen as shown in Table 4 below. Monterey County growers applied the most excess nitrogen, which was primarily to the lettuce crop group. This is closely followed by San Mateo and Santa Cruz counties. It should be noted that these three counties also had the highest percentages of growers with excess application of nitrogen of those reporting.

This data included 15 growers who did not apply any co=ercial fertilizer. Of these, only one applied excess nitrogen because of the high nitrogen content in the irrigation water being used.

Table 4: Fertilizer Application Review by County

County	No. Farms Reporting*	No. Farms w/ Excess N	Excess N Applied (lbs/ac)
MO	13	9	92
SB	7	3	21
SC	39	14	49
SM	13	8	81
SZ	4	4	79
All Counties	76	38	64

•includes 15 farms that did not apply any fertlllzer.

ill PROGRAM ANALYSIS

Sampling & Reporting: In general, taking initial water and soil samples was a fairly simple task and often completed in conjunction with the initial grower meeting. Timely reporting of the results and recommendations of these samples to the growers was limited due to the availability of the growers during the growing season. As a result, reports were often faxed or delivered during the next sampling event.

For the mid-season sampling, timing of reporting was the biggest issue. For the short season growers, it was difficult to get the report back to the grower before harvest. This was mostly an issue for the lettuce and greenhouse/nursery growers.

It was beneficial to have the option to collect mid-season soil samples rather than petiole samples. For some crops, this was more relevant to the scope of the project than tissue samples.

At the end of a crop season, a 0-2 ft soil composite was taken to generate a nitrate profile for the field. Although the full profile could not be compared to the initial sample, it was informative for the growers to see the remaining nitrates in the soil. In some cases, end of season soil samples were not representative because crop land had already be prepared for the next crop, or in the case of greenhouses/nurseries, the crop containers had been removed from the site.

Water Use: Growers were asked to record the amount of water applied to their crop throughout the growing season. Approximately half of the growers provided accurate records of irrigation events. JML provided information on the crop's water requirements along with a water analysis. However, irrigation scheduling was not a focus of this project. Other factors that may affect irrigation scheduling, such as routine moisture soil sampling and precipitation, were not considered when water needs were estimated. However, it was found that the majority of the growers reporting irrigation information were not applying more water than was required to meet ETo requirements.

Irrigation of greenhouse/nursery operations was not addressed as a part of this project. Water use recommendations were based on full season (180 day) crops as opposed to 30-60 days for most greenhouse/nursery crops. Thus, water recommendations could be much different if the crop is only watered for 30-60 days verses 180 days.

Nitrogen Use: In general, growers were interested in learning how to improve nutrient usage for their crops. The program demonstrated to growers that there were more sources of nitrogen to consider than just commercial fertilizer. Some were surprised to find out how much nitrogen was available in the soil and/or irrigation water. Also, the growers were interested in the comparison of the nitrogen applied during the crop season and the nitrogen remaining in the soil after harvest. Overall, this part of the project was definitely beneficial to the growers.

In the greenhouse/nursery operations, it was difficult to track the nitrogen after it was applied. Due to the nature of the plant's environment, watering often leached the nitrogen from the plant containers. This would create a deficit of nitrogen, requiring more nitrogen to be applied. The majority of greenhouse/nursery crops were "harvested" earlier than a full season crop. Another issue for many of the greenhouse/nursery growers is the esthetics of the plant, not just the end of season yield. Because esthetics is a secondary but essential goal for the crop, growers must provide sufficient water and nutrients to the crop to ensure that goal is met.

Cover crops are being used on some fields during the winter season. These cover crops are often used to provide nitrogen for the upcoming crops. Little information was collected about the specifics of the cover crops during the program. Based on some of the testing results, it was obvious that nitrogen fixing cover crops were used, but growers did not always know how much nitrogen these cover crops were providing. Also, if the crop is not harvested, but disked into the field to increase organic matter, over time nitrogen will be released. The rate of release is unpredictable due to many factors, such as weather, soil temperature, microbial activity, etc. This issue was not addressed in the project.

Yield: Many of the growers did not provide yield data for their crops. This data is very important when evaluating nutrient usage during a crop season. A complete nutrient balance is not possible without accounting for the nutrients that were removed in crop residue. It is also difficult to estimate the amount of nitrogen that was "lost" and can not be recovered by upcoming crops. Also, without crop yields, the effectiveness of the growers activities to achieve maximum yield cannot be defined.

IV RECOMMENDATIONS

The following are recommendations for the project and future studies developed by JMLord, Inc. in consultation with SCVWD growers:

I. **Greenhouse/Nursery Operations:** Future studies should address the differences in irrigation practices between greenhouse/nursery operations and other conventional grower operations. These two systems are managed very differently and need to be addressed as such. The greenhouse/nursery crops are typically only on site for a short time before being sold or transplanted to a permanent location. Timing is essential when trying to model nutrient movement through a greenhouse/nursery system. Short turn around times on samples taken is essential to ensure that irrigation and nutrient application modifications can be made before the crop is removed.

   Soil sampling should include both the container and the ground surface below to determine if nutrients are being lost to the ground and could possibly be recovered. Water often leaches from the containers during irrigation events. A sample of this water should be captured and tested for nutrient content providing the grower with information on how much fertilizer is being lost to leaching from the containers. This would allow for better tracking of nutrients through the system and opportunities for recycling of potentially nutrient-rich water.

2. **Crop Group Tracking:** Develop programs to address nutrient and water use issues by crop group. Each crop type has different management strategies which can affect how nutrients and water are tracked through the crop season. For example, lettuce crops are a short season crop and often multiple plantings are grown within a year on the same field. It would be beneficial to not only track one planting oflettuce, but all plantings through the season. This would show growers how the previous crop influences the next and insure the better use of residual nutrients left in the soil after crop harvest. Developing projects by crop type would allow for focused efforts, which would provide individual growers with the information necessary to address more specific water and nutrient issues based on crop selection.

3. **Irrigation Scheduling:** Irrigation scheduling, based on sound data, should be utilized to efficiently use water and soil nutrients. Many growers base irrigation scheduling on historical knowledge of the soil and crop types in conjunction with the "dig and feel" method to check soil moisture. From the grower's viewpoint, the critical factor in irrigation scheduling is crop production. Water conservation is only a secondary concern. A whole system approach to irrigation is needed to help growers to better evaluate crop water needs. In addition to tracking daily rainfall and evaporation, routine soil moisture testing could help identify available moisture or lack of moisture within the soil structure. This combined approach could help the grower apply irrigation water when the plant truly needs it and can use it. This could vastly improve irrigation management and production efficiency in the region.

4. **Soil and Tissue Sampling:** Sampling should be modified and defined to provide more useful information for the type of crop being grown. Although, there was flexibility in this program for sampling; the sampling protocol should be defined by crop group. Tissue samples should only be taken during the growth stages where there is sufficient data to compare to actual values. Also, on many crops, it is not necessary to take tissue samples every two weeks. Typically, one complete leaf sample and up to three petiole samples are more than adequate for full season crops. The initial soil sample should be a profile so it can be compared to the end of season soil profile sampling. Also, depth of soil profile sampling should be based on the crop being grown. For example, vegetable crops may have a maximum root depth of 24 inches, so the profile should extend 12 inches below that maximum root depth. For permanent crops, a soil profile to a depth of 5 feet would be more appropriate.

5. **Cover Crop:** Cover crop usage needs to practices should be addressed. The use of cover crops and their management should be documented to ensure all nutrients in the system are accounted for. Legume cover crops are often used to add nutrients to the soil for the upcoming crop. Soil sampling prior to the next crop needs to be strongly encouraged so a grower knows the effects of the nitrogen fixing crop. Non-Legume cover crops are often used to scavenge nutrients left by the previous crop. The fate of the cover crop at harvest can affect the nutrient availability for future crops. Regardless of which type of cover crop is used, management is different depending on the goal/need of the covercrop.

6. **Organic Crops:** A program should be developed to help organic growers develop nutrient management strategies for alternative nutrient sources conforming to accepted organic practices. Organic growers are limited to the types of products that can be used on the crop. This makes estimating nutrient application and usage more difficult. More nutrient testing may be necessary on amendments, like manure or non-co=ercially packaged products to ensure application rates are correct. In addition to nutrients, education about organic practices to help with pest and weed control would be beneficial to organic farmers and their crops.

7. **Exotic and Specialty Crops:** More data needs to be collected on exotic and specialty crops grown in SCVWD. There currently is limited information available on water needs, nutrient requirements and crop yields for these crops.

8. **Grower Education:** Growers have indicated that they would like education on fertilizer types, application times, pruning, and irrigation scheduling. They would also like direct access to persons with expertise in these fields to better answer their questions.

   A functional program that includes cost, irrigation scheduling and nutrient application efficiency would benefit growers.

V CONCLUSION

Overall, the program was a success. Growers were able to see the impact of their management strategies through the use of soil, tissue and water tests. The nutrient balance at the end of the season demonstrated to growers that they can modify their management practices to reduce the potential for groundwater degradation and also save production cost by more efficiently applying fertilizers.

Total water application to crops in the District appears to be conservative. Growers indicated that they are interested in more information regarding scheduling of irrigation applications.

The program identified a definite need for more education about nitrogen usage and conservation. Several crop types were identified that truly need education programs and new management options to better conserve nitrogen.

The key benefit of the program was that growers were provided with specific information and data that allows them, on a farm by farm basis, to identify management options that will improve their water and fertilizer applications throughout the growing season.

REGIONAL AG MOBILE LAB PROGRAM GROWER SURVEY

Fifty-three Mobile Lab participants were surveyed upon completion of their services. Results from San Mateo, Santa Cruz, Santa Clara, and Monterey Counties were pooled together. The following tables and figures represent these results. For the complete data set, see Appendices – Data.

I. OVERALL VALUE OF THE PROGRAM

The 3rd, 4th, and 11th were broad questions on the value of the program.

3. Was the Program worth your time?	
Yes	92%
No	6%
No response	2%

4. Would you be willing to spend more time on a similar program?	
Yes	89%
No	6%
No response	6%

11. Would you like to see another program like this in the future?	
Yes	91%
No	6%
No Response	4%

Responses from these questions were quite similar and suggest that most growers thought that the Program was not only worth their time but would be worthy of even greater time investments. Most growers wanted to see another Mobile Lab Program in the future.

II. CHANGES MADE AS A RESULT OF THE PROGRAM

The 6th and 7th questions asked participants what changes they might make as a result of information learned from the Program. (See Appendices – Figures for more information.)

6. What changes did you (or will you make) as a result of the contractors' recommendations?	
Began/continued keeping records	38%
Other*	36%
Reduced fertilizer use	34%
Reduced the number of irrigations	21%
Used CIMIS or ET data to determine irrigation schedule	19%
Reduced irrigation time	17%
No response	9%
Reduced pesticide use	2%

*Responses to "Other"

Flush drip lines often	Increase micronutrient applications
Irrigate at night	Used gypsum
Used pressure nozzle and increased irrigations	Increase fertilizer use
Repair inefficient pump	Better timing on fertilizer
Change nozzles/gaskets	Did not understand organic farming
Change pump	Increase irrigation time
Possible E/C conversion	Continue to keep fertilization records
	Will keep irrigation records once the system gets fixed

Responses from the 6th question indicate that more than one third of the Program Participants began keeping records of agricultural inputs and/or reduced their fertilizer inputs. Roughly one fifth of the Program Participants reduced their irrigations, used weather station information to plan irrigations, and/or irrigated for shorter periods. In general, the "Other" responses indicated that growers intended to make improvements to their irrigation systems, make informed decisions on fertilization, and keep better records of agricultural inputs.

7. Do you find the record keeping useful for your farming operation?	
Yes	85%
No	4%
No response	11%

Responses to the 7th question may indicate that the majority of the Mobile Lab Program participants see the value in keeping records of their agricultural inputs.

III. COMMENTS ON PROGRAM DESIGN

The 1st, 2nd, 5th, 8th, and 9th questions gathered information from Participants on the design of this and other grower Programs. (See Appendices – Figures for more information.)

1. Which services did you receive through the program?	
Soil Testing/Nutrient Management	75%
Irrigation System Test	81%
Pump Test	62%

2. How much time did you spend participating in the program?	
0-1 hours/week	75%
1-2 hours/week	17%
2-4 hours/week	8%
4-8 hours/week	0%

5. Would you rather receive the contractors' reports in person or in the mail?	
In Person	58%
In the Mail	55%

8. What type of communication methods do you find effective?	
Phone	64%
Fax	40%
E-mail	55%
World Wide Web/Internet	21%

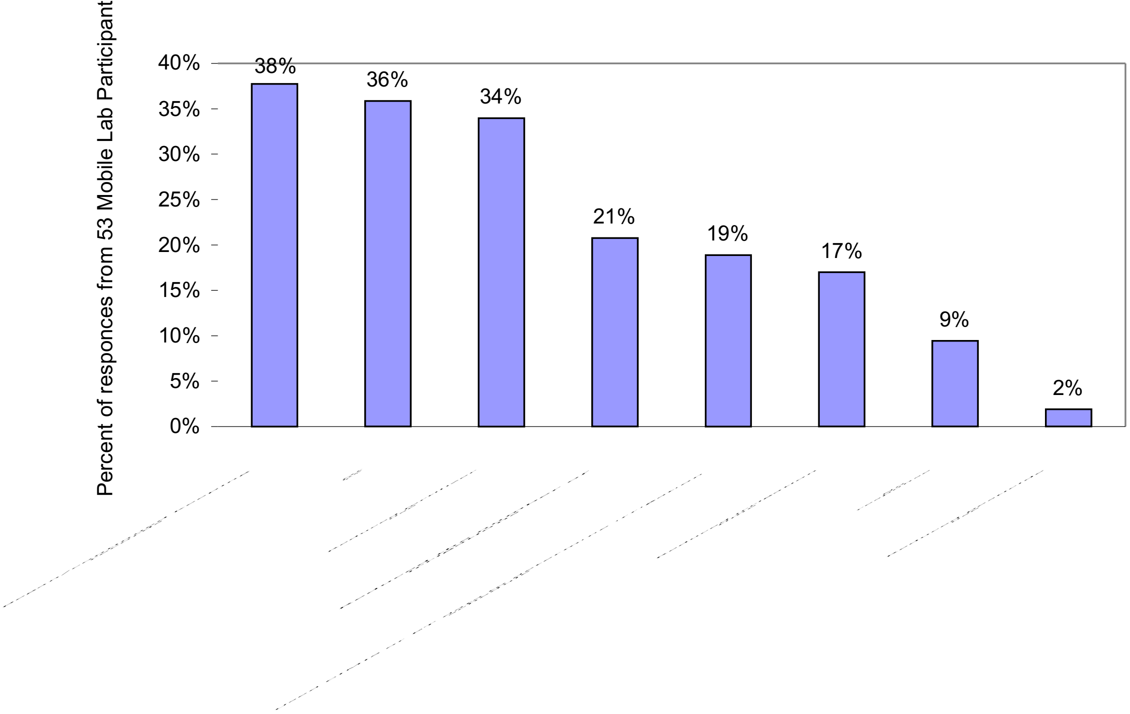
9. Who are good sources of information?	
Farm Bureaus	79%
UC Cooperative	58%
Consultants	57%
Trade Organizations	36%
Water Agency	36%
RCD	26%
Other (not specified)	4%

10. What training opportunities are most useful to you and your organization?	
Tailgate Workshops	34%
Meeting Hall Workshops	60%
Field Demonstrations	77%

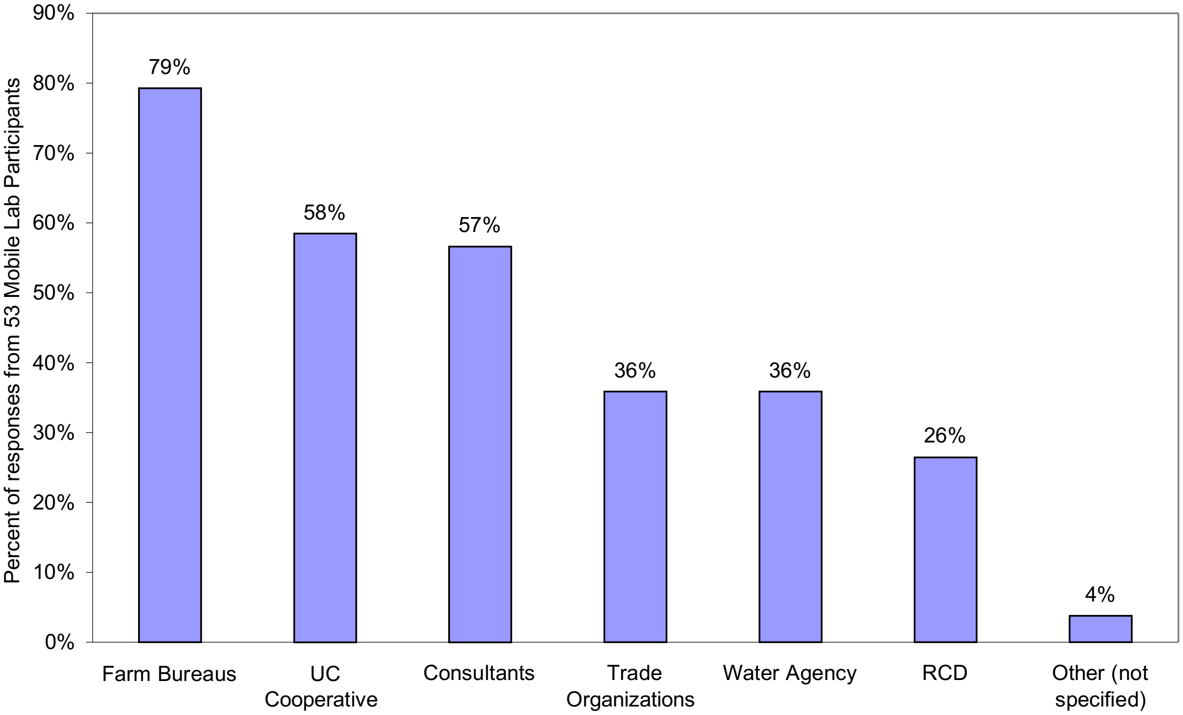
Most growers chose to receive all three Program services. One reason mentioned by growers for not doing a pump test was that pump maintenance was their land lord's responsibility, not their's. Three quarters of the program participants spent an hour or less per week on the program. Responses didn't clearly show a preference for mailing final reports versus going over them in person. However, many growers commented that the follow up meetings were extremely valuable. In decreasing order of preference, growers choose phone, fax, email, and the world wide web as their choices for communication. Farm Bureaus, UC, and Consultants came out as the top information sources for growers. It should be noted that the surveys were administered by Farm Bureau staff in most cases which might have skewed results. Growers may have been confused by the question of what training opportunities are most useful since the difference between “tailgate workshops” and “field demonstrations” was not explained. In general, it seems that growers appreciate an opportunity to come indoors for a short workshop involving facts, figures, and PowerPoint. But, in the end, they enjoy their indoor time to be balanced with outdoor demonstrations, too.

APPENDICES - FIGURES

6. What changes did you (or will you make) as a result of the contractors' recommendations?



9. Who are good sources of information?



APPENDICES – DATA

Survey data for Santa Cruz County (SZ), San Mateo County (SM), Monterey County (MC), and Santa Clara County (SCL). Note that since n<30 for any one county, statistical comparisons between counties cannot be easily made.

	SZ	SM	MC	SCL	**Total**	SZ	SM	MC	SCL	**Mean**
	#					%				
1 Which services did you receive through the program?*										
Soil Testing/Nutrient Management	6	9	8	17	**40**	75%	82%	57%	85%	**75%**
Irrigation System Test	6	10	8	19	**43**	75%	91%	57%	95%	**81%**
Pump Test	6	7	9	11	**33**	75%	64%	64%	55%	**62%**
No response	0	0	0	0	**0**	0%	0%	0%	0%	**0%**
2 How much time did you spend participating in the program?										
0-1 hours/week	6	8	11	15	**40**	75%	73%	79%	75%	**75%**
1-2 hours/week	1	1	3	4	**9**	13%	9%	21%	20%	**17%**
2-4 hours/week	1	2	0	1	**4**	13%	18%	0%	5%	**8%**
4-8 hours/week		0	0	0	**0**	0%	0%	0%	0%	**0%**
No response		0	0	0	**0**	0%	0%	0%	0%	**0%**
3 Was the Program worth your time?										
Yes	8	11	12	18	**49**	100%	100%	86%	90%	**92%**
No		0	2	1	**3**	0%	0%	14%	5%	**6%**
No response	0	0	0	1	**1**	0%	0%	0%	5%	**2%**
4 Would you be willing to spend more time on a similar program?										
Yes	7	11	12	17	**47**	88%	100%	86%	85%	**89%**
No		0	2	1	**3**	0%	0%	14%	5%	**6%**
No response	1	0	0	2	**3**	13%	0%	0%	10%	**6%**
5 Would you rather receive the contractors' reports in person or in the mail?*										
In Person	7	9	5	10	**31**	88%	82%	36%	50%	**58%**
In the Mail	3	3	12	11	**29**	38%	27%	86%	55%	**55%**
No response		0	0	0	**0**	0%	0%	0%	0%	**0%**
6 What changes did you (or will you make) as a result of the contractors' recommendations? *										
Reduced the number of irrigations	0	1	2	8	**11**	0%	9%	14%	40%	**21%**
Reduced irrigation time	1	0	3	5	**9**	13%	0%	21%	25%	**17%**
Used CIMIS or ET data	1	3	2	4	**10**	13%	27%	14%	20%	**19%**
Reduced fertilizer use	1	4	3	10	**18**	13%	36%	21%	50%	**34%**
Reduced pesticide use	0	0	0	1	**1**	0%	0%	0%	5%	**2%**
Began/continued keeping records	7	4	2	7	**20**	88%	36%	14%	35%	**38%**
Other: ____________________	5	3	7	4	**19**	63%	27%	50%	20%	**36%**
No response	0	2	3	0	**5**	0%	18%	21%	0%	**9%**

* indicates that more that multiple selections were allowed

APPENDICES – DATA (CONT.)

	SZ	SM	MC	SCL	**Total**	SZ	SM	MC	SCL	**Mean**
	#					%				
7 **Do you find the record keeping useful for your farming operation?**										
Yes	7	10	13	15	**45**	88%	91%	93%	75%	**85%**
No	0	0	1	1	**2**	0%	0%	7%	5%	**4%**
No response	1	1	0	4	**6**	13%	9%	0%	20%	**11%**
8 **What type of communication methods do you find effective?***										
Phone	6	5	10	13	**34**	75%	45%	71%	65%	**64%**
Fax	1	6	6	8	**21**	13%	55%	43%	40%	**40%**
E-mail	2	6	8	13	**29**	25%	55%	57%	65%	**55%**
World Wide Web/Internet	2	3	0	6	**11**	25%	27%	0%	30%	**21%**
No response	0	0	0	0	**0**	0%	0%	0%	0%	**0%**
9 **Who are good sources of information?**										
Farm Bureaus	7	11	12	12	**42**	88%	100%	86%	60%	**79%**
Trade Organizations	2	5	2	10	**19**	25%	45%	14%	50%	**36%**
RCD	2	5	2	5	**14**	25%	45%	14%	25%	**26%**
UC Cooperative	2	5	8	16	**31**	25%	45%	57%	80%	**58%**
Water Agency	2	0	6	11	**19**	25%	0%	43%	55%	**36%**
Consultants	2	7	7	14	**30**	25%	64%	50%	70%	**57%**
Other	0	0	1	1	**2**	0%	0%	7%	5%	**4%**
No response	0	0	0	0		0%	0%	0%	0%	**0%**
10 **What training opportunities are most useful to you and your organization?***										
Tailgate Workshops	2	4	4	8	**18**	25%	36%	29%	40%	**34%**
Meeting Hall Workshops	6	9	7	10	**32**	75%	82%	50%	50%	**60%**
Field Demonstrations	6	9	12	14	**41**	75%	82%	86%	70%	**77%**
Other	0	0	0	0	**0**	0%	0%	0%	0%	**0%**
No response	0	0	0	0	**0**	0%	0%	0%	0%	**0%**
11 **Would you like to see another program like this in the future?**										
Yes	7	11	12	18	**48**	88%	100%	86%	90%	**91%**
No	0	0	2	1	**3**	0%	0%	14%	5%	**6%**
No Response	1	0	0	1	**2**	13%	0%	0%	5%	**4%**
Totals										
Total number of surveys	8	11	14	20	**53**	100%	100%	100%	100%	**100%**

* indicates that more that multiple selections were allowed

APPENDIX B: Monitoring and Modeling Documents

Regional Integrated Program for Irrigation and Fertilization Management Assistance in Santa Clara, San Benito, Santa Cruz, Monterey, and Santa Mateo Counties.

Final Report for Practice Effectiveness Monitoring

May 1, 2007

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1. Summary

The objective of this project was to compare water quality and nutrient loads from vegetable fields under current, standard practices and under best management practices for water and nutrients. Five sites were identified in the project area in 2005 and 2006 where adjacent fields or blocks in a field were managed under different water and nutrient management strategies. Irrigation management was improved by increasing the distribution uniformity of the irrigation system or by scheduling irrigations using CIMIS evapotranspiration information and soil moisture monitoring. Nutrient management was improved through soil and tissue testing, and following published nutrient recommendations for the specific commodities grown at each site. The project evaluated the amount of nutrients and water used under current and improved management practices, as well as the yield and quality of the produce, and the nutrient and sediment loads from each set of the paired fields or blocks. Nutrients and sediments lost through run-off were measured during irrigation events. Results of paired trials demonstrated that nitrate leaching losses could be reduced by using weather-based irrigation scheduling and soil nitrate testing to determine fertilizer-N requirements, and by supplying fertilizer and water in small but more frequent intervals than are usually used in commercial production. Trials also showed yield losses for celery when water applications were reduced, though amounts applied were more than 50% to 100% greater than crop evapotranspiration requirements.

2. Introduction

The regional integrated program for irrigation and fertilization management assistance was designed to help growers improve irrigation and fertility management practices in Santa Clara, San Benito, Monterey, San Mateo, and Santa Cruz Counties. In order to document the water quality benefits, the Santa Clara Valley Water District contracted public and private entities to develop a robust modeling approach to evaluate the effectiveness of recommended practices to improve water quality. Field monitoring data and modeling tools were used to characterize nutrient loads from land use and to provide recommendations for the Total Maximum Daily Load (TMDL) and Best Management Practices (BMP). By better managing nutrients and irrigation, growers may achieve significant improvements in water quality. This project evaluated practices which increase the efficiency of irrigation and nutrient management on intensively farmed vegetable fields through monitoring of farm water quality and using a dynamic agro-ecosystem model to estimate nitrate leaching. The researchers at the University of New Hampshire and Applied Geosolutions, LLC used a soil biogeochemistry, Denitrification-Decomposition (DNDC) model to predict soil/plant processes and estimate soil water movement and soil nitrogen and carbon processes which determine nitrogen losses from the farming systems.

Acknowledgements: The authors would like to thank the Central Coast Regional Water Quality Control Board and Santa Clara Valley Water District for the opportunity to participate in this project and funding to carry out the monitoring activities. Special thanks to the technical advisor panel that oversaw the project and the many grower cooperators that participated in the on-farm research activities.

3. Summary of Methods

3.1 Overview of field trials

Side by side comparisons were made of standard and improved (best managed) practices for managing nitrogen and water of vegetable crops. Fields, ranging in size of 8 to 12 acres were split into 2 management blocks: best management practices (BMP) and grower standard (GS) practices. The improved or "best" practices evaluated depended on the vegetable commodity and grower interest. Water and nutrient use were monitored in the BMP and GS blocks. Water quality was evaluated through a combination of direct analysis of soil and water samples and through model analysis of collected data.

3.2 Irrigation efficiency

Irrigation efficiency was evaluated in each field/block by measuring the amount of applied water using a flow meter. Crop water requirements were estimated using CIMIS data and estimates of crop canopy cover, determined with an infra-red camera. Irrigation efficiency was calculated as:

$$Irrigation\ Efficiency = \frac{crop\ water\ requirement}{total\ water\ applied} \times 100 \qquad [1]$$

where crop water requirement and total water applied are in units of inches.

3.3 Soil moisture

Soil moisture was monitored in each field using watermark granular matrix blocks to document that an adequate amount of moisture was applied to the fields. An estimate of water stored in the soil profile was made by measuring the volumetric soil moisture content at the start and the end of the crop cycle using a neutron hydroprobe.

3.4 Estimates of drainage

The relative contribution of run-off and deep percolation to irrigation losses was estimated from direct measurements of run-off during irrigation events and by estimating drainage using equation 2:

$$Total\ Water Applied = Crop\ ET + Runoff + Drainage + \Delta Water\ \ Storage\ \ in\ Soil \qquad [2]$$

where ET is evapotranspiration, Δ Water Storage is the change in water stored in the soil profile, and all variables are in units of inches.

3.5 Run-off volume

Water volume was measured with a flume for each sprinkler irrigation event that generated runoff. The height of the water in the flume was measured in the stilling well using a float mechanism that was interfaced with a datalogger. Water height in the flume was recorded at 5 second intervals and averaged every 5 minutes by the datalogger. The water height data were converted to flow rate using the manufacturer's calibration equation. The total volume of run-off can be calculated by integrating the flow rates during the entire irrigation event.

3.6 Irrigation runoff

Samples of field run-off were collected using a peristaltic pump during irrigation events. When run-off occurs above 5 gallons per minute, the pump was be activated by a datalogger at 5 minute intervals to collect a 20-200 ml sample. The sample size was proportioned to the flow rate to produce an accurate composite sample of the run-off water.

3.7 Soil nitrate

Soil nitrate levels in the soil profile of each field were characterized to a 36-inch depth in the soil profile at 12-inch depth increments by the consulting agronomist on a weekly basis. These samples were collected from 10 fixed sample locations or stations in each of the management treatments. Rapid analysis of these samples by the agronomy consultant was used to determine weekly soil nitrate status in the management ‘treatments’ and to guide the agronomist and grower participant in adjusting weekly N fertigation schedules for the BMP treatment. These data are also to be supplied to Geosolutions for model calibration.

3.8 DNDC modeling

The researchers at the University of New Hampshire and Applied Geosolutions, LLC estimated nitrogen losses for the BMP and grower standard managed blocks using a soil biogeochemistry, Denitrification-Decomposition (DNDC) model. This model predicts soil/plant processes to provide a robust understanding of soil water movement and soil nitrogen and carbon processes which determine nitrogen losses from the farming systems.

4. Results of Practice Effectiveness Monitoring

4.1 Best Practices for Managing Water and Nitrogen in Celery: 2005

4.1.1 Trial Summary

Objective: Evaluate best management practices for water and nitrogen fertilizer management in celery.

Best Management Practices Evaluated:

1. CIMIS weather-based irrigation scheduling.
2. Reduced N fertilizer applications

Growing Dates: 6/3/05-8/27/05
Location: Gilroy CA

4.1.2 Crop water use

Crop ET was estimated using infra-red canopy photos and reference ET data averaged from the nearest CIMIS stations (Morgan Hill, San Juan, and San Benito). Estimates of canopy cover for celery during the season are summarized in Figure 4.1. Cumulative crop ET was estimated to be 10.5 inches between transplanting and harvest for both management blocks (Table 4.1). Irrigation was scheduled in the best management practices (BMP) block using crop ET and soil moisture monitoring after the drip system was installed, between July 5th and August 27th. A total of 18 inches of water were applied to the BMP block and 22.6 inches were applied to the grower standard (GS) block using overhead impact sprinklers and surface drip. Approximately 5 inches were applied using sprinklers to the BMP block and almost 8 inches were applied to the GS block. The reduced application of water increased irrigation efficiency from 46% in the GS block to 58% in the BMP block (Table 4.1). No run-off was measured during the season, including when overhead sprinklers were used for pre-irrigation and to establish transplants. Soil moisture in the 0 to 1 foot depth was maintained between 0 and 40 cbars in the BMP block and between 0 and 80 cbars in the GS block (Figure 4.2), indicating that celery may have experienced more water stress than in the GS block.

4.1.3 Crop yield and quality

The highest biomass and marketable yields were measured in the GS block, where more water was applied (Table 4.2). However, water use efficiency (biomass/applied water) was slightly higher in the BMP block. The quality defect, pith, was slightly lower in the BMP block, compared to the GS block.

4.1.4 Applied Nitrogen

A total of 367 lb of N/acre were applied to the GS block and 303 lb of N/acre were applied to the BMP block. Nitrogen fertilizer was applied preplant, shanked in after stand establishment, and applied through the drip system. Nitrate in the irrigation water was approximately 7.8 ppm nitrate-N.

4.1.5 Drainage and nitrate leaching

Estimated drainage was 8.2 and 13 inches for the BMP and GS blocks, respectively, sufficient amounts to leach nitrate into the ground water (Table 4.1). Increases in the level of the shallow water table underneath the field that coincided with irrigation events were direct evidence of drainage below the root zone of the crop (Fig. 4.2). Nitrate levels ranged between 20 and 60 ppm nitrate-N in ground water samples collected from 3 to 4 foot depths in the BMP and GS blocks (Fig. 4.3). Soil nitrate levels were generally similar in the BMP and GS blocks. Nitrate levels were as high as 46 ppm nitrate-N in the top 1-foot layer for both blocks and ranged between 10 and 20 ppm-N in at the 3 foot depth.

4.1.6 DNDC modeling

Model results estimated that the nitrate leaching was 33 and 54 lb of N/acre for the BMP and GS blocks (Table 4.3). Nitrogen lost by denitrification was estimated to be 6 and 4 lbs/acre for the GS and BMP blocks, respectively.

Table 4.1 Water use summary for celery in BMP and grower standard blocks, 2005

Treatment	Applied Water	Crop ET	Runoff	Δ Soil Moisture	Drainage	Irrigation Efficiency
	-----------------------------		inches		-----------------------------	%
BMP	18.0	10.5	0.0	-0.6	8.2	58.1
Grower Standard	22.6	10.5	0.0	-0.9	13.0	46.3

Table 4.2 Celery biomass and marketable yield in BMP and grower standard blocks, 2005

Treatment	Total Biomass	Marketable Biomass	Pith	Water Use Efficiency
	------ tons/acre -----		%	tons/inch
BMP	48.4	31.8	31.7	2.69
Grower Standard	58.2	37.7	35.0	2.58

Table 4.3 DNDC modeling of nitrate leaching and denitrification losses for trial sites managed under best practices and grower standard practices

Management Practice	Nitrate Leaching Losses		Denitrification Losses	
	kg of N/ha	lb of N/acre	kg of N/ha	lb of N/acre
	------------------ celery 2005 -----------------------			
Grower Standard	60	54	7	6
Best Management Practice	37	33	5	4
	------------------- spinach 2005 -----------------------			
Grower Standard	45	40	0	0
Best Management Practice	57	51	0	0
	--------------------- celery 2006 -----------------------			
Grower Standard	407	363	5	5
Best Management Practice	196	175	2	2
	------------------- spinach 2006 -----------------------			
Grower Standard	2	2	0	0
Best Management Practice	3	3	0	0
	------------- Brussels sprouts 2006 -------------			
Grower Standard	73	65	10	9
Best Management Practice	31	28	7	6
	----------------- Average --------------------			
Grower Standard	117	105	4	4
Best Management Practice	65	58	3	2

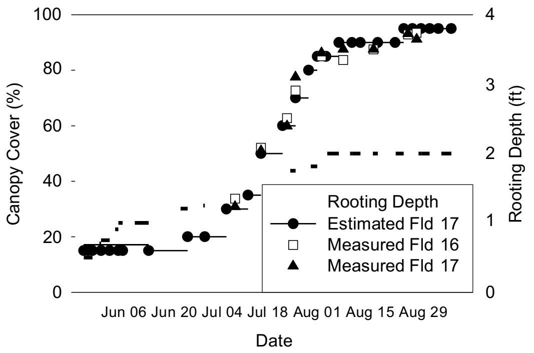

Figure 4.1 Crop canopy cover measured in the BMP (field 17) and GS (field 16) blocks. Rooting depth measurements were averaged for both blocks.

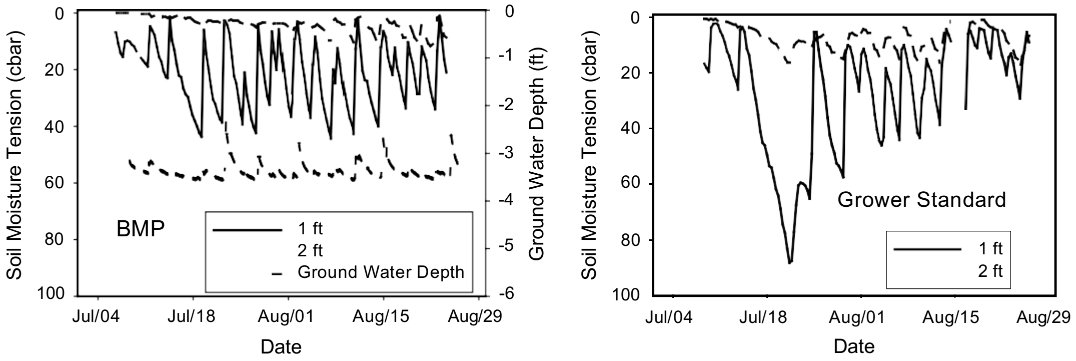

Figure 4.2. Soil moisture tension in best management practice and grower standard blocks. Ground water levels are presented for the best management practice block.

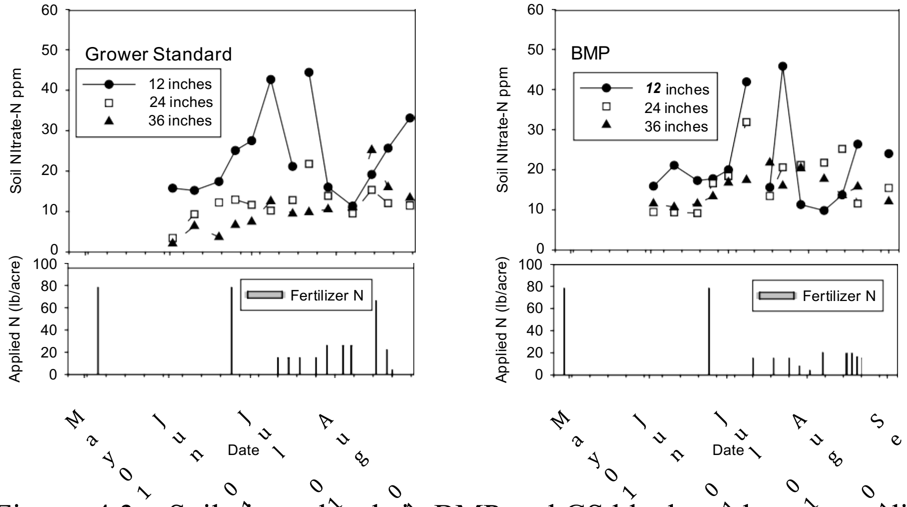

Figure 4.3 Soil nitrate levels in BMP and GS blocks and corresponding nitrogen fertilizer applications.

4.2 Best Practices for Reducing Run-off and Nitrate Leaching in Baby Spinach: 2005

4.2.1 Trial Summary

Objective: Evaluate best management practices for water and nitrogen fertilizer management in Spinach.

Best Management Practices Evaluated:

1. Polyacrylamide for improving quality of irrigation run-off
2. Reduced applied water

Growing Dates: 9/15/05-10/17/05
Location: Gilroy, CA

4.2.2 Crop water use

Crop ET was estimated using reference ET data averaged from the nearest CIMIS stations (Morgan Hill, San Juan, and San Benito) and from estimates of the crop coefficient for spinach. Cumulative crop ET was estimated to be 3.4 inches between seeding and harvest for both blocks (Table 3.1). The crop was irrigated by overhead sprinklers that had a distribution uniformity of 82%. Irrigation was scheduled by the grower in both blocks; however, less water was applied in the BMP block during each irrigation. A total of 4.5 inches of water were applied to the BMP block and 5.5 inches were applied to the grower standard (GS). The reduced application of water increased irrigation efficiency from 62% in the GS block to 75% in the BMP block. Soil moisture was monitored using a neutron probe at the beginning and end of the trial to evaluate soil moisture storage.

4.2.3 Crop yield and quality

The highest biomass and marketable yields were measured in the GS block, where more water was applied. Water use efficiency (biomass/applied water) was 0.8 tons per inch of applied water in the BMP block and 1.0 tons per inch of applied water in the GS block. Yield estimates were made approximately 4 days before commercial harvest.

4.2.4 Applied nitrogen

A total of 100 lb of N/acre were applied to the GS and the BMP blocks in 3 applications. A majority of the nitrogen (68 lb of N/acre) was applied before planting. Nitrogen fertilizer was applied preplant, shanked in after stand establishment, and applied through the drip system. Nitrate in the irrigation water was approximately 7.8 ppm nitrate-N.

4.2.5 Drainage and nitrate leaching

Estimates of deep drainage (below 3 feet) were slightly negative, suggesting that it was a minor component of water loss during irrigation events, and nitrate leaching would have been minimal during the crop production (Table 4.4). Nitrate-N levels ranged from 20 to 40 ppm in the upper 6 inches of the soil profile for both blocks (Fig. 4.4). Nitrate levels at the 2 foot depth were slightly higher in the BMP compared to the GS block, and generally ranged from 5 to 20 ppm of nitrate-N.

4.2.6 DNDC modeling

Model results estimated that N losses due to nitrate leaching were 40 and 51 lbs of N/acre for the GS and BMP blocks, respectively (Table 4.3). Nitrogen lost by denitrification was negligible for both management blocks.

4.2.7 Irrigation run-off

Irrigation run-off represented a significant loss of the water applied with the sprinklers. Run-off was 1.6 inches (35% of applied water) in the BMP block and 1.9 inches (35% of applied water) in the GS block (Table 4.4). Polyacrylamide (PAM), injected to achieve a 5 ppm concentration in the irrigation water, reduced suspended sediment and turbidity levels in the run-off by 96% and 98%, respectively (Table 4.6). The reduction in sediment levels in the BMP run-off reduced the cumulative loss of soil by 370 lbs/acre (Table 4.7). Total N and total P were reduced by 69% and 70%, respectively. PAM did not reduce levels of soluble P and nitrate in the run-off water.

Table 4.4. Water use summary for spinach in BMP and grower standard blocks, 2005

Treatment	Applied Water	Crop ET	Runoff	Δ Soil Moisture	Drainage	Irrigation Efficiency
	------	------	inches	------	------	%
BMP	4.5	3.4	1.6	-0.1	-0.3	74.5
Grower Standard	5.5	3.4	1.9	0.5	-0.3	61.2

Table 4.5 Spinach yield in BMP and grower standard blocks, 2005

Treatment	Bulk Yield	Water Use Efficiency[x]
	tons/acre	tons/inch
BMP	3.5	0.8
Grower Standard	5.3	1.0

[x] water use efficiency = bulk yield/applied water

Table 4.6. Sediment and nutrient concentration in run-off from BMP and grower standard blocks for individual irrigation events in 2005

Treatment	Total N (TKN)	NO3-N	P (Soluble)	P (Total)	Total Suspended Solids	Turbidity
	mg/L					NTU
9/15/05						
Grower Standard	9.9	8.3	2.0	8.2	6500	6821
BMP	2.4	7.5	1.2	1.7	180	86
9/16/05						
Grower Standard	4.0	6.9	1.1	3.3	1450	2044
BMP	1.3	6.7	0.8	0.9	31	11
9/17/05						
Grower Standard	3.6	7.8	1.2	3.2	1530	2064
BMP	0.9	7.1	0.8	0.8	39	34
9/18/05						
Grower Standard	6.0	7.9	1.8	5.8	2590	3597
BMP	2.2	8.8	1.2	2.5	1142	665
9/19/05						
Grower Standard	3.6	7.4	1.2	3.8	1968	1530
BMP	1.0	8.8	0.9	1.0	111	39
9/20/05						
Grower Standard	2.4	7.7	1.2	2.8	987	1524
BMP	1.0	10.0	1.0	1.0	19	43
9/21/05						
Grower Standard	2.0	7.1	1.2	2.6	923	1318
BMP	0.6	8.1	0.8	0.8	38	26
9/27/05						
Grower Standard	6.2	7.1	1.5	4.0	3095	3966
BMP	1.3	9.6	0.8	1.1	135	53
Avg (Grower Standardl)	4.0	6.5	1.2	3.5	2057	2408
Avg (BMP)	1.2	8.1	0.9	1.0	74	42
% Reduction	69	--	23	70	96	98

Table 4.7. Sediment and nutrient loads in run-off from BMP and grower standard blocks, 2005

Treatment	Total Suspended Sediments	Total N	Nitrate-N	Total Phosphate	Ortho-Phosphate
	lb per acre-inch of runoff				
BMP	37.7	0.29	1.86	0.26	0.21
Grower Standard	409.1	0.81	1.69	0.84	0.29

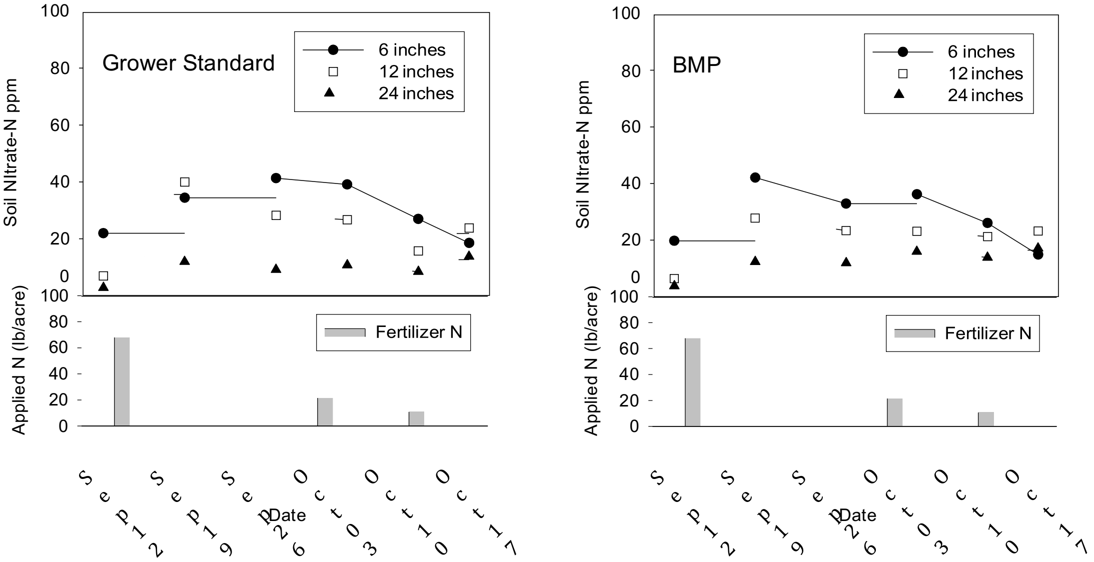

Figure 4.4. Soil nitrate levels in BMP and GS blocks and corresponding nitrogen fertilizer applications.

4.3 Best Practices (BMP) for Managing Water and Nitrogen in Celery: 2006

4.3.1 Trial summary

Objective: Evaluate best management practices for water and nitrogen fertilizer management in celery.

Best Management Practices Evaluated:

1. CIMIS weather-based irrigation scheduling.
2. Reduced N fertilizer applications

Growing Dates: 5/18/06-8/10/06
Location: Gilroy CA

4.3.2 Crop water use

Crop ET was estimated using infra-red canopy photos and reference ET data averaged from the nearest CIMIS stations (Morgan Hill, San Juan, and San Benito). Cumulative crop ET was estimated to be 10.5 inches between transplanting and harvest for both blocks (Table 4.8). Irrigation was scheduled in the BMP block using crop ET and soil moisture monitoring after the drip system was installed, between June 16th and August 7th. A total of 28.1 inches of water were applied to the BMP block and 29.4 inches were applied to the grower standard (GS) block using overhead impact sprinklers and surface drip. Approximately 12 inches of water were applied using sprinklers to the BMP and GS blocks. Irrigation efficiency was 38% in the BMP block and 36% in the GS block (Table 4.8). Both irrigation efficiencies were lower than measured for the same treatments during the 2005 season. Total run-off from overhead sprinklers was 0.6 inches for both blocks. Soil moisture at the 8 inch depth was generally maintained between 0 and 40 cbars in the BMP block and between 0 and 60 cbars in the GS block (Fig. 4.5). Soil moisture at the 18 inch depth declined in both blocks during July, but moisture levels became driest in the BMP block.

4.3.3 Crop yield and quality

The biomass yields were similar in the GS and BMP blocks (~50 tons/acre); however, marketable yield was highest for the GS block (Table 4.9). Water use efficiency (biomass/applied water) was slightly higher in the BMP block (1.82 tons/inch for the BMP treatment and 1.75 tons/inch for the GS treatment). The quality defect, pith, was less (40%) in the BMP block, compared to the GS block (88%).

4.3.4 Applied nitrogen

A total of 661 lb of N/acre were applied to the GS block and 390 lb of N/acre were applied to the BMP block. Nitrogen fertilizer was applied preplant, topdressed after transplanting, and applied through the drip system. Total nitrogen fertilizer applied through the drip system was 453 lb/acre for the GS block and 260 lb/acre for the BMP block. Nitrate in the irrigation water was approximately 7.8 ppm nitrate-N.

4.3.5 Drainage and nitrate leaching

Estimated drainage was 17 and 18.9 inches for the BMP and GS blocks (Table 4.8), respectively, sufficient amounts to leach nitrate below the 3 foot root zone. Soil nitrate levels were generally similar in the BMP and GS blocks (Fig. 4.6). Nitrate levels were as high as 35 ppm nitrate-N in the top 1-foot layer for both blocks and ranged between 8 and 23 ppm nitrate-N at the 3 foot depth.

4.3.6 DNDC modeling

Model results estimated that the nitrate leaching resulted in losses of 363 and 174 lbs of N/acre for the GS and BMP blocks, respectively (Table 4.3). Denitrification losses were 5 and 2 lb of N/acre for the GS and BMP blocks, respectively.

4.3.7 Irrigation run-off

Total irrigation run-off from overhead sprinkler applications was 0.6 inches, or 5% of the sprinkler applied water for the BMP and GS blocks, and represented a minor loss of the water and nutrients for the crop cycle.

Table 4.8. Water use summary for celery in BMP and grower standard blocks, 2006

Treatment	Applied Water	Crop ET	Runoff	Δ Soil Moisture	Drainage	Irrigation Efficiency
	------------------------------	inches	------------------------------			%
BMP	28.1	10.5	0.6	-0.06	17.0	37.5
Grower Standard	29.4	10.5	0.6	-0.63	18.9	35.7

Table 4.9. Celery biomass and marketable yield in BMP and grower standard blocks, 2006

Treatment	Total Biomass	Marketable Biomass	Pith	Water Use Efficiency[x]
	------ tons/acre -----		%	tons/inch
BMP	51.0	33.3	40.0	1.82
Grower Standard	51.4	37.1	88.3	1.75

[x] water use efficiency = total biomass/applied water

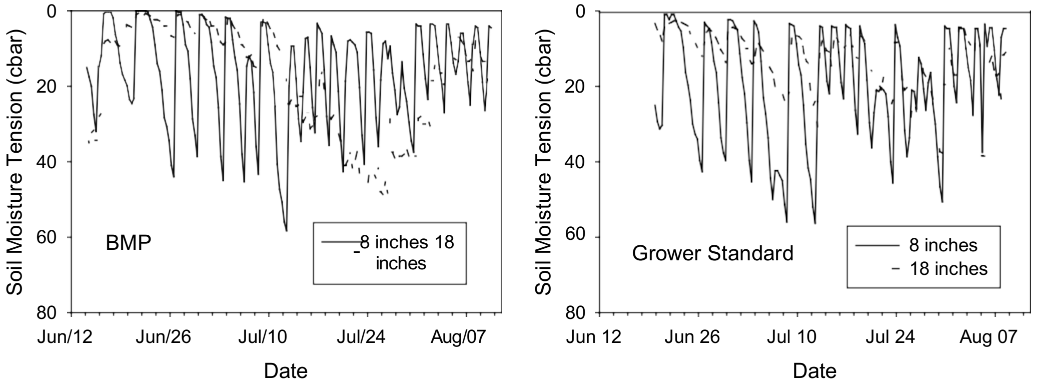

Figure 4.5. Soil moisture tension in BMP and Grower Standard Blocks at 8 and 18 inch depths.

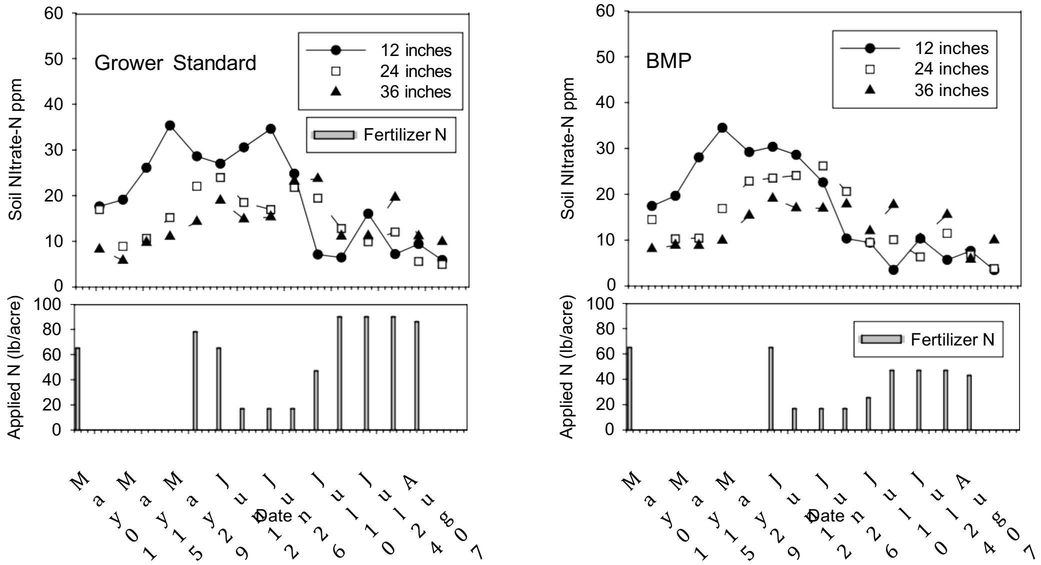

Figure 4.6. Soil nitrate levels in BMP and GS blocks and corresponding nitrogen fertilizer applications.

4.4 Best Management Practices (BMP) for Reducing Run-off and Nitrate Leaching in Baby Spinach: 2006

4.4.1 Trial summary

Objective: Evaluate best management practices for water and nitrogen fertilizer management in Spinach.

Best Management Practices Evaluated:

1. Polyacrylamide for improving quality of irrigation run-off

Growing Dates: 7/22/06-8/12/06
Location: Gilroy, CA

4.4.2 Crop water use

Crop ET was estimated using reference ET data averaged from the nearest CIMIS stations (Morgan Hill, San Juan, and San Benito) and from estimates of the crop coefficient for spinach. Cumulative crop ET was estimated to be 3 inches between seeding and harvest for both blocks (Table 4.10). The crop was irrigated with overhead sprinklers that had a distribution uniformity of 82%. Irrigation was scheduled by the grower in both blocks. A total of 5.2 inches of water were applied to the BMP block and 5.1 inches were applied to the grower standard (GS) block (Table 4.10). Irrigation efficiency averaged 58% for the GS and BMP blocks. Soil moisture was monitored using a neutron probe at the beginning and end of the trial to evaluate soil moisture storage to estimate moisture storage in the soil profile.

4.4.3 Crop yield and quality

Spinach biomass yields were 6.5 tons/acre in the BMP block and 6.6 tons/acre in the GS block (Table 4.11). Water use efficiency (biomass/applied water) was 1.2 tons per inch of applied water in the BMP block and 1.3 tons per inch of applied water in the GS block.

4.4.4 Applied nitrogen

A total of 129 lb of N/acre were applied to the GS and the BMP blocks in 3 applications. A majority of the nitrogen (107 lb of N/acre) was applied before planting. Nitrogen fertilizer was applied preplant, topdressed on the bed, and applied through the drip system. Nitrate in the irrigation water was approximately 7.8 ppm nitrate-N.

4.4.5 Drainage and nitrate leaching

Estimates of deep drainage (below 3 feet) were 2 inches for the BMP block and 1.5 inches for the GS block (Table 4.10). Polyacrylamide, applied through the irrigation water to the BMP block may have increased infiltration, thereby increasing drainage. Although drainage represented an important source of water loss during irrigation events, the amount of water drained through the soil profile was minimal and probably would not be major source of nitrate leaching during the crop cycle. Nitrate-N levels ranged from 20 to 60 ppm in the upper 6 inches of the soil profile for both blocks, with highest levels measured in the GS block (Fig. 4.7). Nitrate levels at the 2 foot depth were similar in the BMP and GS blocks, and generally ranged from 5 to 16 ppm of nitrate-N.

4.4.6 DNDC modeling

Model results estimated that the nitrate leaching resulted in losses of 2 and 3 lbs of N/acre for the GS and BMP blocks, respectively (Table 4.3). Denitrification losses were negligible for both blocks.

4.4.7 Irrigation run-off

In comparison to drainage, irrigation run-off represented a minor loss of the applied water. Run-off was 0.13 inches (2.5% of applied water) in the BMP block and 0.49 inches (9.5% of applied water) in the GS block. The lower amount of run-off from the BMP block may be attributable to polyacrylamide (PAM), injected into the irrigation water to achieve a 5 ppm concentration. PAM also reduced suspended sediment levels in the run-off from the BMP block by 99% (Table 4.12). The reduction in sediment levels in the BMP run-off reduced the cumulative loss of soil by 168 lbs/acre per inch of run-off compared to the GS block. Total N, ammonium-N and nitrate-N were reduced by 89%, 87%, and 83%, respectively. PAM also reduced levels of soluble P in the run-off by 77% (Table 4.12).

Table 4.10 Water use summary for spinach in BMP and grower standard blocks, 2006.

Treatment	Applied Water	Crop ET	Runoff	Δ Soil Moisture	Drainage	Irrigation Efficiency
	------------------------------	------------------------------	inches	------------------------------	------------------------------	%
BMP	5.24	2.99	0.13	0.11	2.02	57.04
Grower Standard	5.11	2.99	0.49	0.15	1.48	58.45

Table 4.11 Spinach yield in BMP and grower standard blocks, 2005

Treatment	Bulk Yield	Water Use Efficiency[x]
	tons/acre	tons/inch
BMP	6.5	1.2
Grower Standard	6.6	1.3

[x] water use efficiency = bulk yield/applied water

Table 4.12 Sediment and nutrient loads in run-off from BMP and grower standard blocks, 2006

Treatment	Total Suspended Sediments	Total N	Ammonium-N	Nitrate-N	Ortho-Phosphate
	------------------ lb per acre-inch of runoff			--------------------	
BMP	1.5	0.15	0.15	1.07	0.06
Grower Standard	169.9	1.41	1.20	6.29	0.28

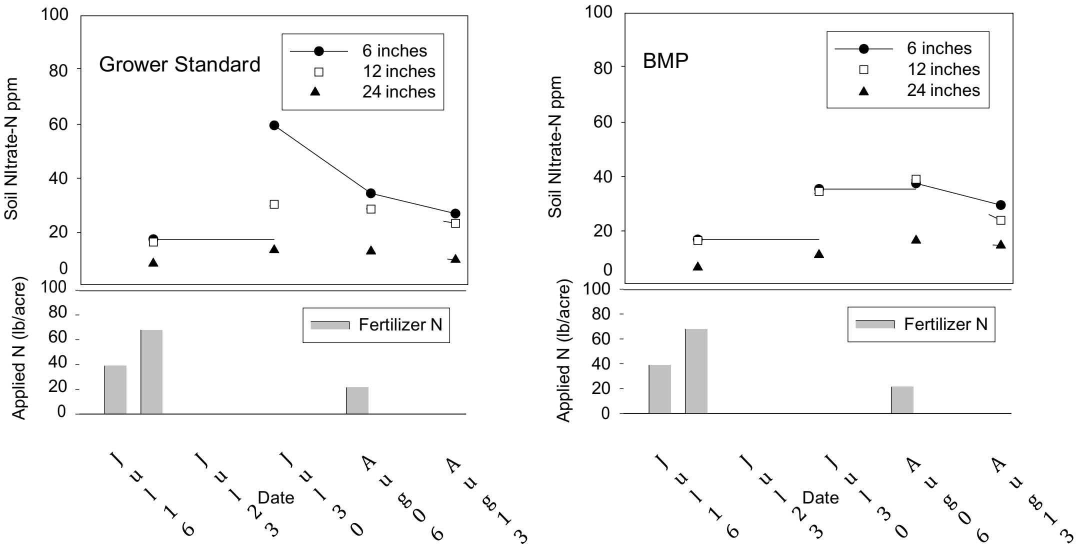

Figure 4.7. Soil nitrate levels in BMP and GS blocks and corresponding nitrogen fertilizer applications.

4.5 Best Practices (BMP) for Managing Water and Nitrogen of Brussels Sprouts: 2006

4.5.1 Trial summary

Objective: Evaluate best management practices for water and nitrogen fertilizer management in Brussels sprouts.

Best Management Practices Evaluated:

1. Subsurface drip irrigation
2. CIMIS weather-based irrigation scheduling.
3. Reduced N fertilizer applications
4. Fertigation of N fertilizer

Growing Dates: 6/28/06-12/05/06
Location: Ano Nuevo, CA

4.5.2 Crop water use

Crop ET was estimated using infra-red canopy photos (Fig. 4.8) and reference ET data averaged from the nearest CIMIS stations (Santa Cruz, Pajaro). Cumulative crop ET was estimated to be 13.7 inches between transplanting and harvest for both blocks (Table 4.13). Irrigation was scheduled in the BMP block using crop ET and soil moisture monitoring after the drip system was installed, between July 12 and December 5th. A total of 12.3 inches of water were applied to the BMP block by overhead sprinklers and drip and 12.7 inches were applied to the grower standard (GS) block using overhead impact sprinklers. Rain events added an additional 2 inches of water to the crop during October and November. Irrigation efficiency was 96% for the BMP and GS blocks. No run-off was measured from either management block. Soil moisture at the 8 inch and 18 inch depths of the GS block was drier than measured in the BMP block (Fig. 4.9). Soil moisture at the 8 inch depth was generally maintained between 20 and 60 cbars in the BMP block and between 40 and 100 cbars in the GS block. Soil moisture at the 18 inch depth was also highest in the BMP block. Soil moisture declined in both blocks during October, but rain events raised moisture levels in November.

4.5.3 Crop yield and quality

Bulk (biomass) and marketable yields were highest in the BMP block. Yield increases in the BMP block were presumably due to less culled sprouts and greater small-sized sprouts than harvested in the GS block (Table 4.14). Water use efficiency (biomass/applied water) was slightly higher in the BMP block (1.0 tons/inch for the BMP treatment and 0.9 tons/inch for the GS treatment).

4.5.4 Applied Nitrogen

A total of 247 lb of N/acre were applied to the GS block and 228 lb of N/acre were applied to the BMP block. All nitrogen fertilizer was applied through the drip system for the BMP block at weekly intervals of 7 to 24 lbs of N per acre until the end of September (Table 4.15). A majority of the N fertilizer (189 lbs of N/acre) was sidedressed in the GS block, and the remaining fertilizer was applied by injection through the sprinklers.

4.5.5 Drainage and nitrate leaching

Estimated drainage was approximately 0.6 and 0.5 inches for the BMP and GS blocks, respectively, assuming soil moisture storage was 0 (Table 4.13). The low amount of drainage in both blocks would not be expected to cause large losses of N through nitrate leaching during the cropping cycle. Nevertheless, soil nitrate levels in the GS block were much higher than levels measured in the BMP block during the season; and therefore nitrate was most likely to leach below the root zone in the GS block if subsequent winter rains were heavy. Highest soil nitrate-N levels were 240 ppm at the 1 foot depth in the GS block during August (Fig. 4.10). Subsequent samples demonstrated that nitrate levels at the 2 and 3 foot depths reached 49 and 23 ppm, respectively, in the GS block during September.

4.5.6 DNDC modeling

Model results estimated that the nitrate leaching resulted in losses of 65 and 28 lbs of N/acre for the GS and BMP blocks, respectively (Table 4.3). Denitrification losses were 9 and 4 lbs of N/acre for GS and BMP blocks respectively.

Table 4.13. Water use summary for Brussels sprouts in BMP and grower standard blocks, 2006.

Treatment	Applied Water[x]	Crop ET	Runoff	Δ Soil Moisture [y]	Drainage	Irrigation Efficiency
	------------------------------	------------------------------	inches	------------------------------	------------------------------	%
BMP	14.3	13.7	0.0	--	0.6	96.0
Grower Standard	14.2	13.7	0.0	--	0.5	96.2

[x] includes 1.97 inches of rainfall

[y] not estimated

Table 4.14. Brussels sprout biomass and marketable yield in BMP and grower standard blocks, 2006.

Treatment	Bulk Yield	Marketable Yield	Large size	Small Size	Culls	Water Use Efficiency[x]
	---- tons/acre	----	--------- %	----------		tons/inch
BMP	14.8	10.7	28.7	43.6	28.5	1.0
Grower Standard	13.0	8.8	31.7	34.7	37.7	0.9

[x] water use efficiency = bulk yield/applied water

Table 4.15. Nitrogen fertilizer applications in BMP and grower standard blocks.

BMP			Grower Standard		
	Applied N			Applied N	
date	Rate	Cumulative	date	Rate	Cumulative
	--------- lb/acre	--------		------ lb/acre	--------
12-Jul	6.3	6.3	10-Jul	38.8	38.8
17-Jul	6.3	12.6	20-Jul	189.0	227.8
21-Jul	3.2	15.8	9-Oct	13.5	241.3
29-Jul	5.3	21.0			
2-Aug	18.9	39.9			
8-Aug	11.8	51.7			
12-Aug	11.8	63.5			
15-Aug	7.1	70.6			
18-Aug	11.8	82.4			
23-Aug	14.2	96.6			
28-Aug	16.6	113.2			
4-Sep	19.8	133.0			
8-Sep	24.4	157.3			
12-Sep	17.6	175.0			
16-Sep	22.9	197.8			
25-Sep	29.7	227.5			

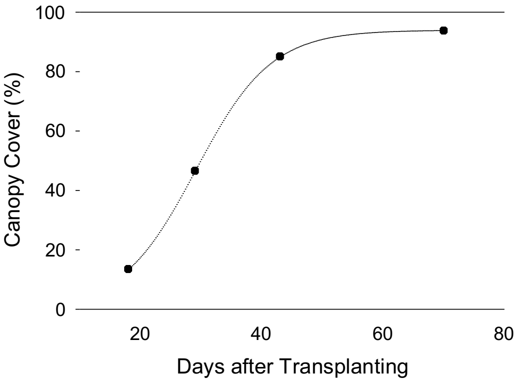

Figure 4.8. Crop canopy cover measured in the BMP block using infra-red photos.

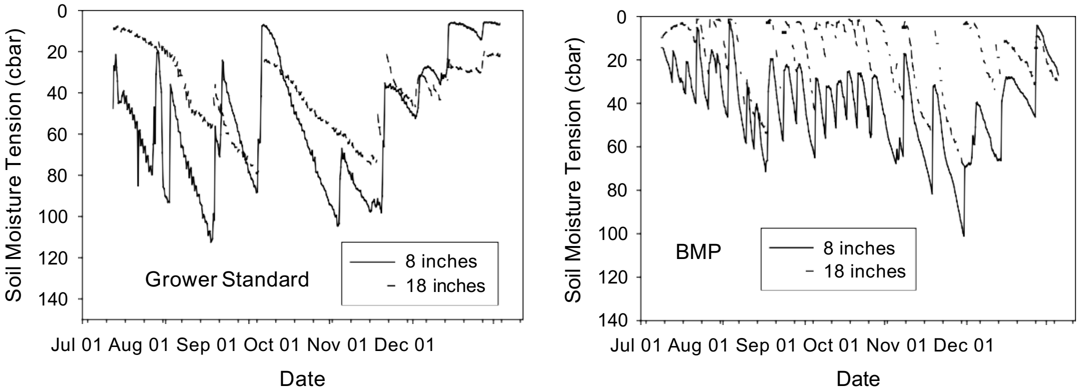

Figure 4.9. Soil moisture tension in best management practice and grower standard blocks.

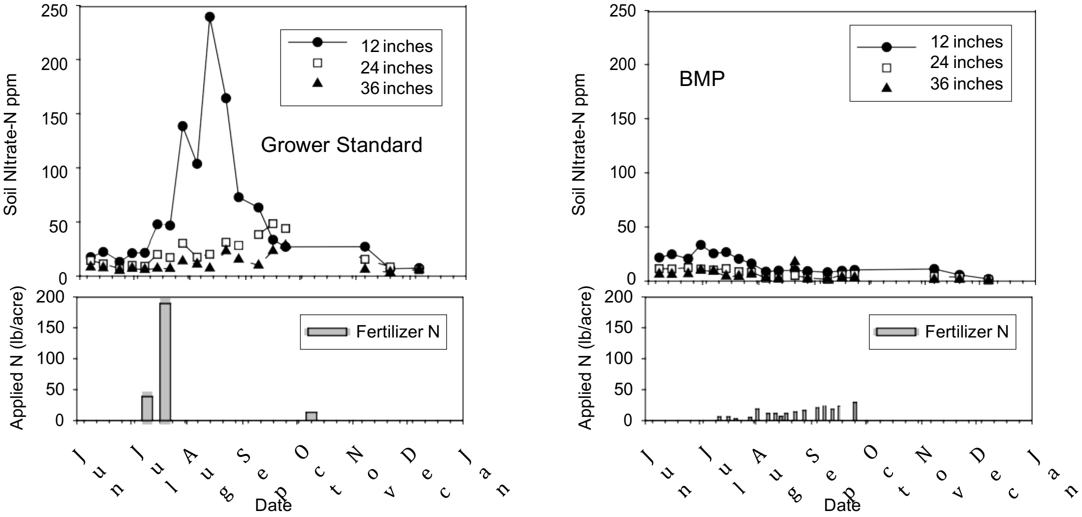

Figure 4.10. Soil nitrate levels in BMP and GS blocks and corresponding nitrogen fertilizer applications.

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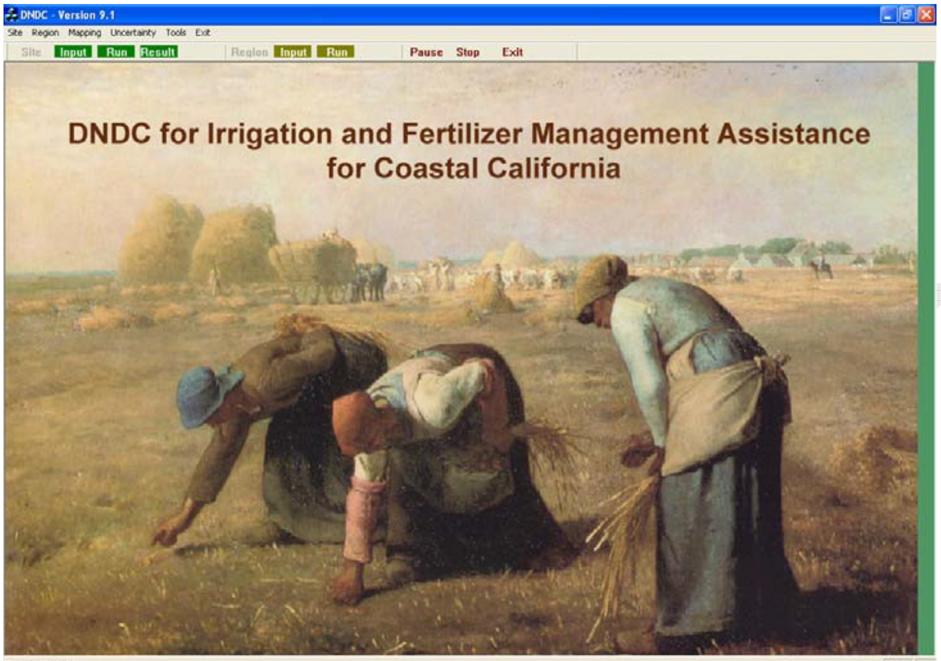
Application of the DNDC Model for the Regional Integrated Program for Irrigation and Fertilization Management Assistance



DNDC for Irrigation and Fertilizer Management Assistance for Coastal California

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DRAFT for Review

April 20, 2007

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1. Background

Nitrate nitrogen leaching from agricultural land is a significant source of nutrient enrichment in coastal ecosystems across the U.S (NOAA 1995). New field monitoring data together with application of modeling tools, are needed to characterize nutrient loads from land use and to provide recommendations for the Total Maximum Daily Load (TMDL) and Best Management Practices (BMP). For this purpose, and in support of the Regional Integrated Program for Irrigation and Fertilization Management in Santa Clara, San Benito, Monterey, San Mateo and Santa Cruz Counties, a dynamic agro-ecosystem model, DNDC, will contribute to estimate the efficiency of current and alternative irrigation and fertilization programs.

Contemporary agriculture is in a transition from single-goal to multi-goal management systems. Optimum yield is not the sole criterion for assessing the success of agricultural production. Instead, concerns about the impacts of agricultural activities on soil fertility, water resources, and environmental safety are now included in assessments of best management practices (Tilman et al., 2002). A crucial task for implementing multi-goal management involves building the capacity to quantify the simultaneous impacts of any single or combined alternative practices on crop yield, soil carbon storage, nutrient leaching and greenhouse gas emissions. Most agro-ecosystems are complex systems, within which climatic, soil and management factors intricately interact. Field experiments play a key role in obtaining first-hand information about the effects of alternative management practices on crop yield and various carbon (C) or nitrogen (N) pools or fluxes in the concerned fields. However, most field experiments require extensive time and resources. To extrapolate the understandings gained at a limited number of field sites to regional scales, process-based models have been developed and adopted to the assist policy making process in agricultural studies (Ahuja et al., 2002). During the past decade, a number of agro-ecosystem models were developed that incorporate the complex interactions among climate, soil, plant growth and management practices. The modeling efforts have provided opportunities to assess the best management practice strategies in a range of scales from individual farms to watersheds and regions (Tsuji et al., 1994; Ahuja et al. 2000; Zhang et al., 2002; Donner and Kucharik, 2003; Li et al., 2006). Among these modeling efforts, the process-based,

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biogeochemical model, Denitrification-Decomposition or DNDC, was developed originally for estimating greenhouse gas emissions from U.S. agricultural lands (Li et al., 1992). This model was recently modified to enhance its capacity in predicting crop growth and yield, simulating discharge flow from tile-drained fields, and quantifying nitrate leaching while accounting for the soil buffering effect of ammonium (Li et al., 2006).

2. DNDC Model

The core of DNDC is a soil-biogeochemisty model which has been linked to vegetation models to simulate soil organic carbon (SOC) dynamics, nitrate leaching dynamics, emissions of nitrogen gases (N_2) and several trace gases including N_2O, NO, NH_3 and CH_4 from agricultural ecosystems. DNDC consists of the six sub-models for soil climate, crop growth, decomposition, nitrification, denitrification, and fermentation. The six interacting sub-models have included the fundamental factors and reactions, which integrate carbon and nitrogen cycles into a computing system (Li et al. 1992, Li 2000, Zhang et al. 2001). DNDC simulates N leaching by integrating soil N dynamics based on soil biogeochemical processes and water dynamics that are controlled by rainfall, irrigation, evapotranspiration and infiltration (Li et al., 2006; Farahbakhshazad et al., 2007).

2.1 Modeling Soil Moisture Dynamics

DNDC simulates soil moisture dynamics by mainly tracking water movement in vertical dimension in soil profile from the surface to a depth of 0.5 m (Figure 1). DNDC has a one-dimensional soil water flow to calculate average hourly and daily soil moisture profile. The default thickness of modeled soil profile is 50 cm. DNDC characterizes soil physical properties by soil texture, following the work of Clapp and Hornberger (1978). The soil profile is divided into a series of horizontal layers. Typical vertical spatial resolution is 2 cm and time step is an hour. Each layer is assumed to have uniform texture and moisture. For each time step, water flow between layers is determined by the gradients of soil water potential (Ritchie et al., 1988). During a simulated rainfall event, rainwater is added on the surface of the soil then infiltrates into the soil profile layer by layer to fill the soil pore. Gravity drainage occurs when the soil

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moisture is higher than the field capacity in a layer. Water efflux from the bottom of the modeled profile is driven by gravity drainage only (Van Bavel et al., 1978). If the rainfall intensity, which is fixed as 0.5 cm/hr in DNDC, and irrigation is higher than the soil saturated hydraulic conductivity, ponding water will form on the soil surface and a surface runoff flow will be calculated based on the defined soil slope. Water withdrawal from the soil profile is calculated based on transpiration and evaporation. Potential evapotranspiration (ET) is calculated as daily average values using the Thornthwaite formula, in which potential ET is determined by mean air temperature and then adjusted for daylight length relative to 12 hours (Dunne and Leopold, 1978). Potential ET is separated into potential transpiration and evaporation. Daily potential transpiration is determined by daily water demand by plants, which is quantified based on the modeled daily increment of crop biomass. Actual plant transpiration is jointly determined by potential transpiration and soil water content. Potential evaporation is the difference of potential ET and actual transpiration. Evaporation is allowed to occur only for the top 20 cm of soil profile. By tracking precipitation, plant interception, ponding water, surface runoff, infiltration, gravity drainage, transpiration, and evaporation, DNDC simulates water movement in the vertical dimension of soil profiles. Detailed descriptions of the hydrological equations and

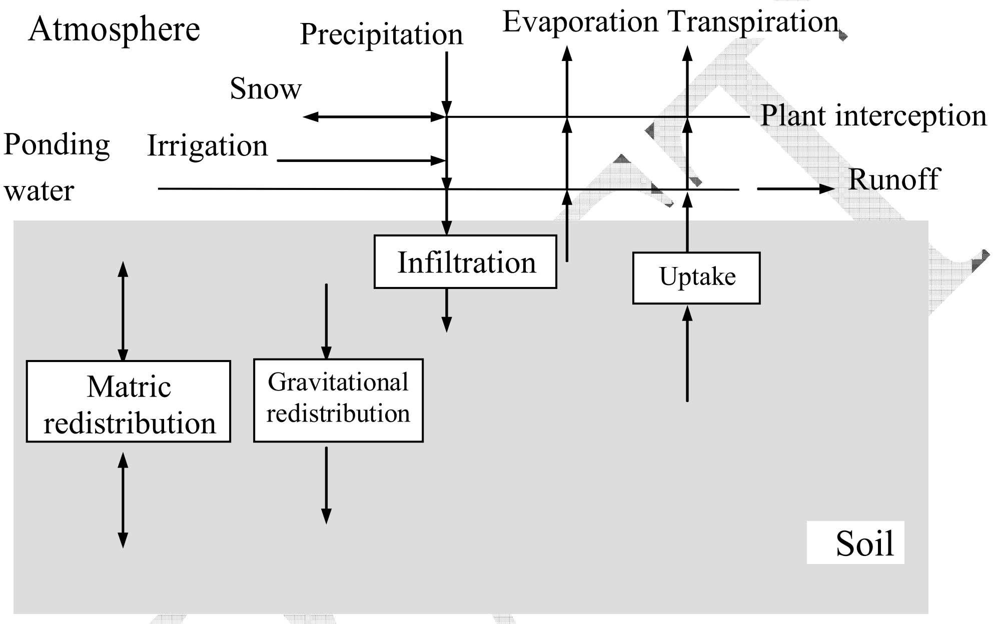

Figure 1 DNDC tracks soil moisture dynamics by primarily simulating vertical water movement in top 0.5 meters of the soil profile.

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parameters have been reported in several former publications (e.g., Li et al., 1992; Zhang et al., 2002 a,b). DNDC was recently modified by adding a water recession curve and a virtual deep water pool to improve predictions of water leaching (Li et al. 2006). An example of DNDC predicted and measured temporal dynamics and magnitude of water leaching fluxes over a four year period for a row-crop field in Iowa is illustrated in Figure 2.

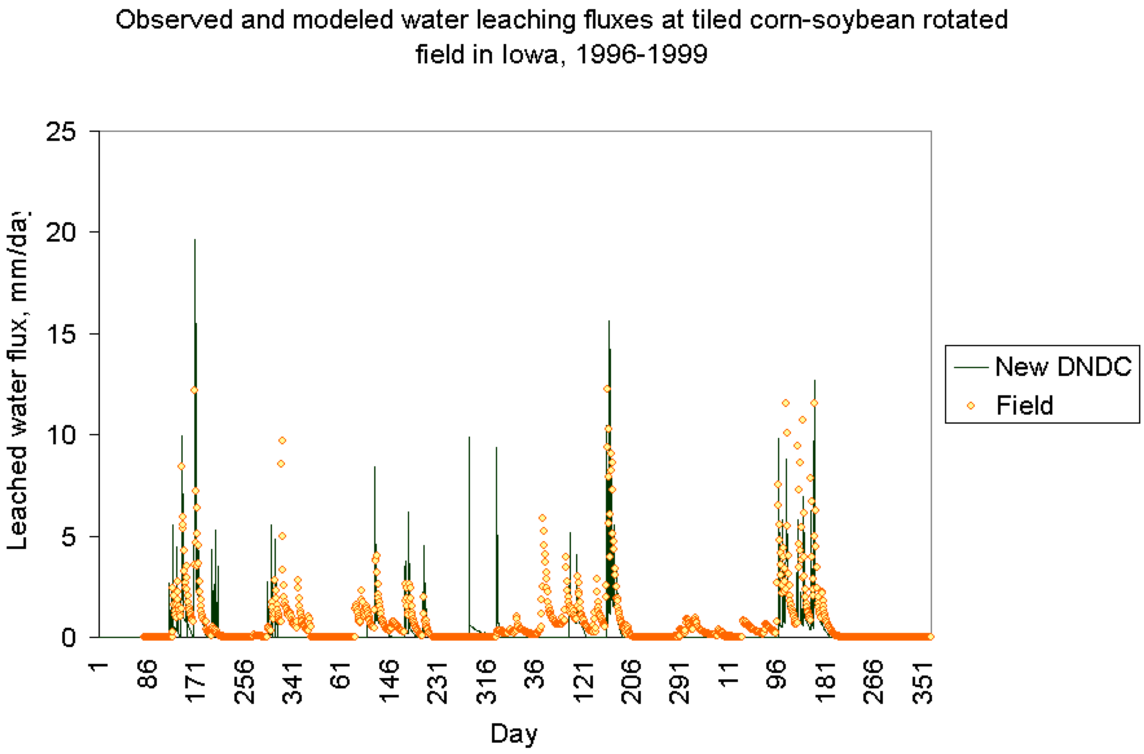

Figure 2 Comparison of DNDC modeled and observed leaching fluxes from tile drains (Source: Li et al. 2006)

2.2 Modeling Nitrogen Dynamics

DNDC models soil N dynamics by precisely tracking several biogeochemical processes involving nitrogen, namely decomposition, ammonification, ammonium-ammonia equilibrium, microbial assimilation, plant uptake, ammonia volatilization, nitrification, and denitrification (Li et al., 1992; Li 2000). In DNDC, when fresh litter is incorporated in the soils, it will be partitioned into the soil organic matter pools, which possess different quality (i.e., C/N ratio) and hence different specific decomposition rates. Litter will be first assimilated into soil microbial biomass. During the assimilation, the microbes demand free NH_4^+ or NO_3^- ions from the soil environment due to the difference in C/N ratio between the microbes and litter. After death of the microbes, they will turn into humus. Active humus can further transfer to passive humus through the microbial activity. During the decomposing processes, a part of organic N is redistributed into the soil organic pools, and other part is turned into NH_4^+ through ammonification. The free NH_4^+ ions dissolved in the soil liquid phase can be absorbed by the plant roots, adsorbed by clay, or oxidized to NO_3^- by the nitrifiers. The schematic in figure 3 is a generalization of N pools and fluxes simulated by DNDC.

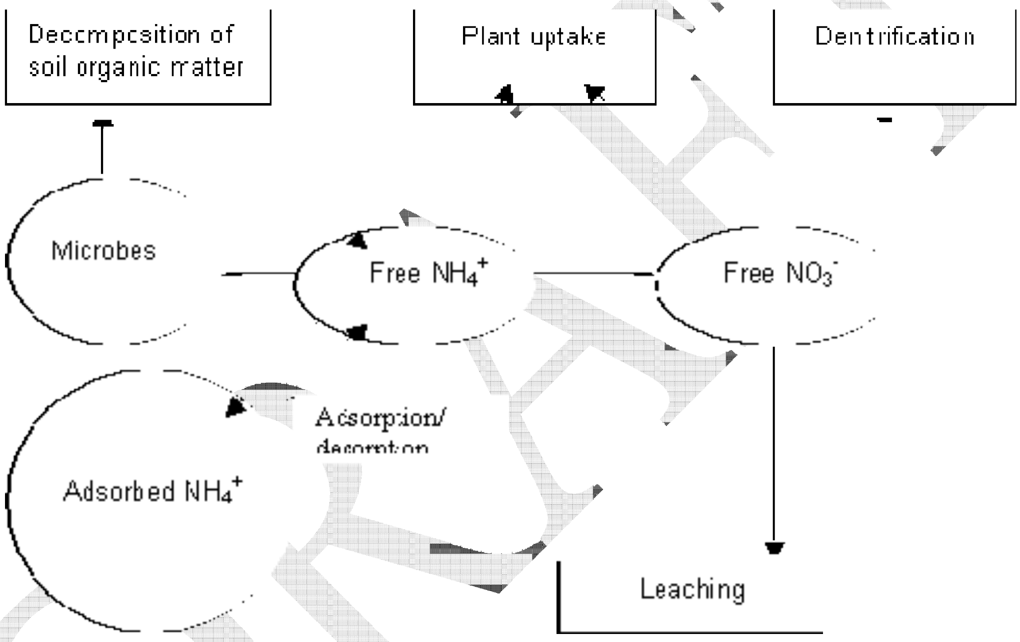

Figure 3 Major Nitrogen Pools and Fluxes simulated in DNDC.

In DNDC, management practices affect N leaching by altering soil water fluxes, nitrogen cycling and nitrate content. Examples are fertilizer application which directly adds N compounds into the soil or irrigation which effects moisture contend, water transport and N movement in the soil.

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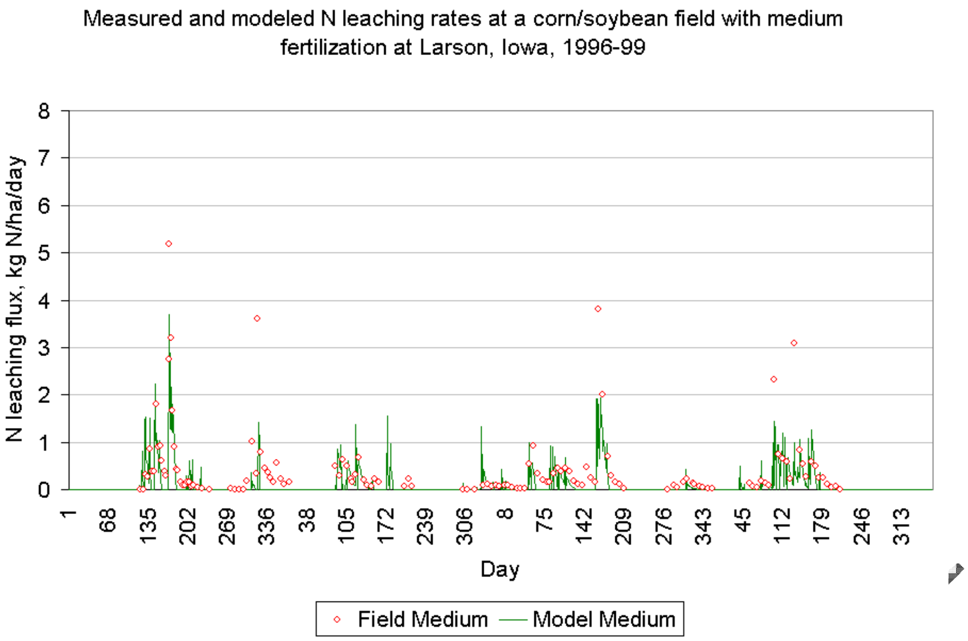

Figure 4 DNDC model comparison with observed N leaching (from Li et al. 2006)

The most recent efforts in refining DNDC were carried out for midwestern agriculture and focused on improving model parameters for the region's specific soil textures and hydrologic systems. Model applicability was tested using long-term measurement data of water and nitrate-N leaching from the row-crop farm fields in Iowa and Illinois (Li et al., 2006; Tonitto et al., 2006a,b). The efforts resulted in several modifications of the model. The one-dimensional water movement algorithm in DNDC was modified for the tile-drained soils by adopting a water discharge recession curve, based on Tallaksen (1995), where the depth of saturation decreases gradually with a decrease in precipitation. The processes governing nitrate-N leaching were modified by adopting the Langmuir equation to quantify adsorption and desorption of ammonium ions on clay and organic matter (Li et al., 2006). The modified features of water flow and nitrate-N leaching, working in conjunction with the functions originally existing in DNDC, enhanced its capacity for predicting impacts of management practices on agricultural production and the environment simultaneously. The improved DNDC was utilized in this study to explore the mechanisms underlying the simultaneous impacts of alternative practices on crop yield, SOC storage, nitrate-N leaching and N gas emissions for Coastal California agricultural lands.

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2.3 DNDC input parameters and output results

In order to simulate nutrient cycling in a specific farm field, DNDC requires a set of input information about climate and site characteristics. Climate information consists of daily maximum and minimum temperatures and daily rainfall. For this study, we processed climate data from Morgan Hill, San Juan and DeLaveaga CIMIS stations for 2005 and 2006. Soil information includes soil texture, pH, bulk density, carbon and nitrogen contents and hydrological characteristics. These soil data were collected for 4 of the trials. For the Brussels sprouts trial (Site 5) we estimated the soil parameters based on the NRCS SSURGO soils database. DNDC requires detailed information of the cropping practices including type of crops, planting and harvesting dates, type, amount, application method and date of fertilizer or manure application; type and dates of tillage; and type, amount and dates of irrigation practices. All of the input data are entered via a user-friendly interface before the simulation, so that the users can easily review the information and make modifications with any of the input parameters to create new scenarios.

When the input procedure is accomplished, the model simulates the dynamics of meteorological conditions, soil climate and chemistry, crop growth, gas emissions and nitrate leaching. By comparing the modeled results with the different scenarios, the users can easily judge how to change their management practices to minimize N leaching from their farm fields.

3. Modeling Objectives and Model Modifications

The objective of this modeling analysis is to assess how the various irrigation and fertilizer management practices impact nitrate leaching. The goal to improve our general qualitative understanding whether the BMPs selected for these fields will impact N leaching in comparison with the grower’s nominal practices (which we refer to as the control). At this point we can only make qualitative assessments because the DNDC model has not been rigorously validated with a wide range of observations (e.g., soil N pools and fluxes) under the Coastal California conditions (e.g. local soil properties, climate, geomorphology, etc). Thus our objectives are to

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assess if the BMPs will lead to a significant increase, decrease or have no effect on total N leaching.

Accurately simulating crop growth is a precondition for modeling soil N dynamics as crops take water and N from the soil during the growing season and hence alter the soil moisture and N regimes during and after the growing season that eventually affect the soil N pools and fluxes including nitrate leaching. In order to implement the proposed simulations, we established three new crops (celery, baby spinach and Brussels sprouts), which were planted in the studied fields in Santa Clara Valley but didn't exist as defaults in the original DNDC. In addition, several new features were built up in DNDC to allow it to fully utilize the data observed in the fields to support the simulations. The details of the modifications are described as follows:

- DNDC simulates crop growth based on a series of physiological and phenology parameters for each crop, which are stored in the crop library files. There are about 50 crops available in the DNDC library files. However, encountering new crops beyond the default library is common. To support users to easily create new crops or modify existing crops for simulation, we developed a sub-model "Crop Creator" in DNDC. This tool allows users to create a new crop library file for a new crop by defining its optimum yield, biomass partitioning, C/N ratio, water and heat requirement, and N fixation capacity. For this project, the celery, baby spinach and Brussels sprouts planted at the studied sites in Santa Clara Valley were created based on their optimum yields, biomass partitioning and C/N ratio observed in situ.
- A new function was added in DNDC to allow users to define soil inorganic N ($NO3^-$ and NH4+) profiles based on observed $NO3^-$ and NH4+ concentrations at various depths. DNDC starts simulations always at the beginning of the calendar year with a series of boundary conditions or internal parameters (e.g., initial $NO3^-$ and NH4+ contents, soil organic carbon partitioning etc.) and may produce $NO3^-$ and NH4+ profiles differing from the observed $NO3^-$ and NH4+ profiles for a specific day. In addition, ignoring the farming practices prior to the interested crop season also introduces uncertainty for the modeled N fluxes occurring during the targeted season. A new feature was developed in DNDC to allow the model to read in the observed $NO3^-$ and NH4+ concentrations at different depths on a user-defined date and utilize the observations to replace the model-

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predicted soil inorganic N (SIN) profiles. Thus, the simulations of the relevant biogeochemical processes after the specific date will be based on the observed SIN profiles.

- Deep tillage of the soils is common in this region. Grower's often rip the soils down to a depth of almost 1 meter. As described in the DNDC model section, DNDC simulates N biogeochemical cycling for the top 50cm of soil, which is where most, if not all, of the microbial processes occur. Therefore, we add new tillage depth (45cm).
- Distribution Uniformity Tool. Distribution uniformity is a statistical estimate of how uniformly irrigation water is applied to the field. We built a tool for automatically creating multiple DNDC input files for assessing the impact of various distribution uniformities (DU) on estimates of N leaching. We assumed that the distribution of the application of irrigation water is normally distributed. Given the DU factor is the mean of bottom receiving irrigation water, we estimate the standard deviation of the distribution based on the z-score for the bottom quartile (1.26889). Since the z-score is on a normal curve with a mean of 0 (offset in amount of irrigation water applied) and a standard deviation of 1. So we can estimate the shape of the distribution curve by calculating the standard deviation (stddev = (DU-mean) /1.26889. So based on the user input DU and number of simulations, the software adjusts the amount of the irrigation water across the range of expect values. Use of this DU tool will be discussed as part of the review process of this draft report.

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4. DNDC Testing

While DNDC has been tested and used for nitrate leaching studies in the MidWest, additional testing was assessed for our field trials. A summary of the findings from the 2005 Celery trial is provided here.

4.1 Crop Growth Dynamics:

DNDC uses an ecophysiological process growth model developed by Penning de Vries et al. (1989) to simulate crop growth. The model use a suite of parameters for simulating plant growth, including, for example, carbon and nitrogen allocation, water requirements, light use efficiencies, and optimum yield. In addition, for each crop we estimate the fraction of total biomass that is harvested, which in turn indicates the amount of crop residue. Some values for these parameters were collected from the field measurements. Other parameters, such a thermal degree days required for crop to reach maturity were estimated by calibrating the model to the observed changes in biomass development. The model parameters used for each crop is provided in the appendix and the project CD-ROM. Comparison of the 2005 celery field measured biomass and DNDC modeled development exhibited a general correspondence, however the modeled biomass development was a bit slower during the rapid growth stage of development (Figure 5).

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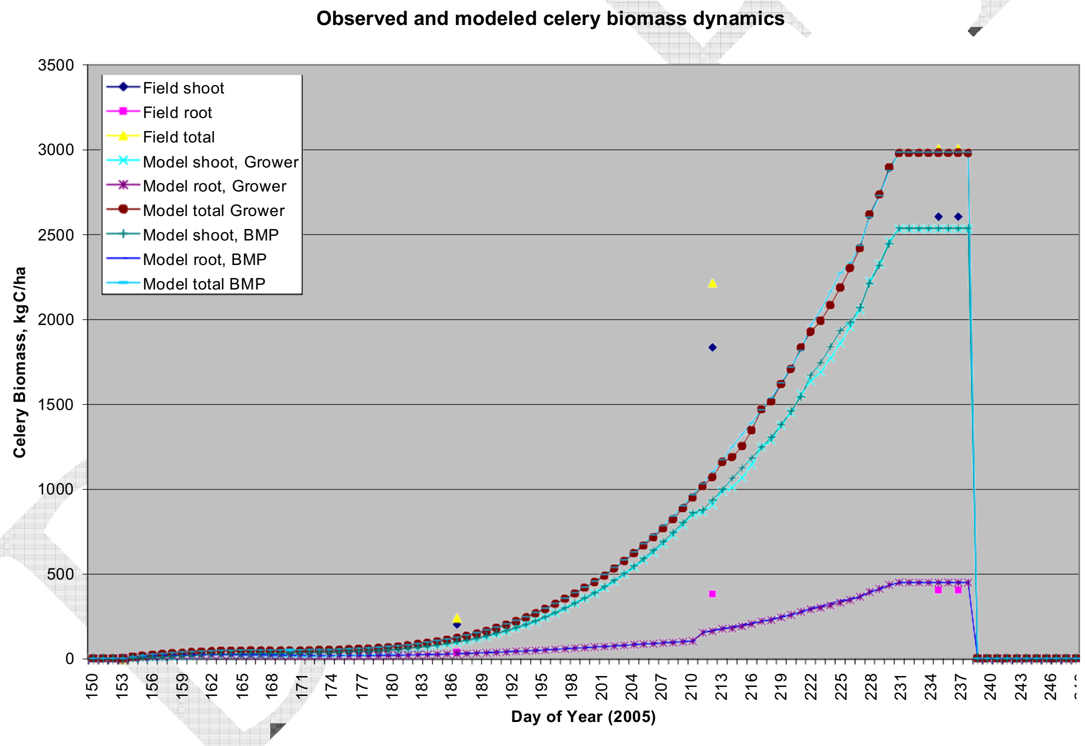

Figure 5 Modeled versus observed celery crop development.

4.2 *Soil Moisture:*

Soil moisture tension was collected at 8 hour intervals from July 6, 2005 through August 23, 2005. In addition, volumetric soil moisture data were collected on June 2nd and August 26th using a neutron probe. Soil moisture release curves (example for the control site, Field 16, is provided in Figure 6) were derived from the soil analysis provided by DANR lab. These soil moisture release curves were used to estimate volumetric soil moisture content from the 8 hour soil moisture tension data.

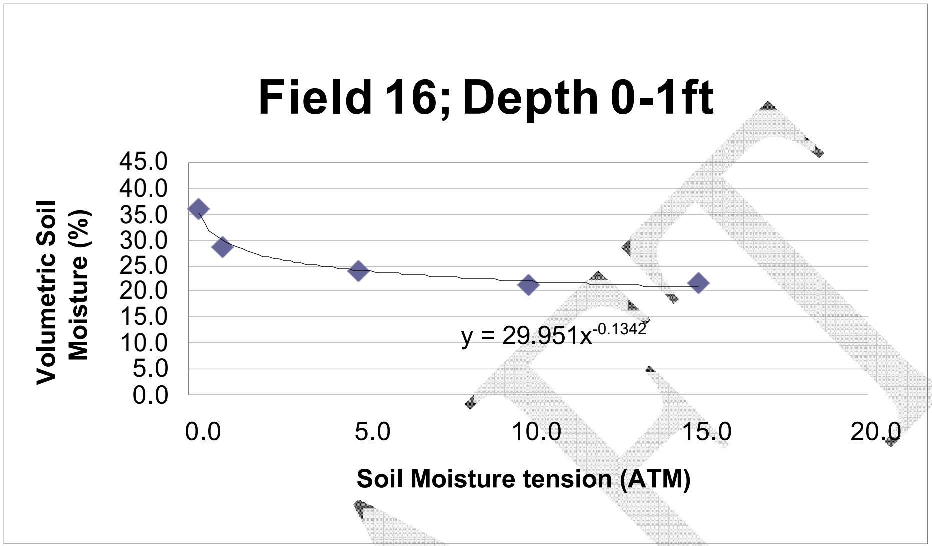

Figure 6 Water release curve for control field celery 2005 trial.

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Figures 7 and 8 present the comparison between daily field and DNDC modeled estimates of soil moisture (expressed as water-filled pore space). While the field based measurements exhibited higher variability, the DNDC modeled soil moisture varied in the range of observations for 0-30 cm depth. The modeled soil moisture in the deeper layer (30-60cm) exhibited very little temporal dynamics in contrast to the measured soil moisture. This discrepancy at the 30-60cm depth is likely due incorrect characterization of the heterogeneity of soil structure or texture in the deep layers.

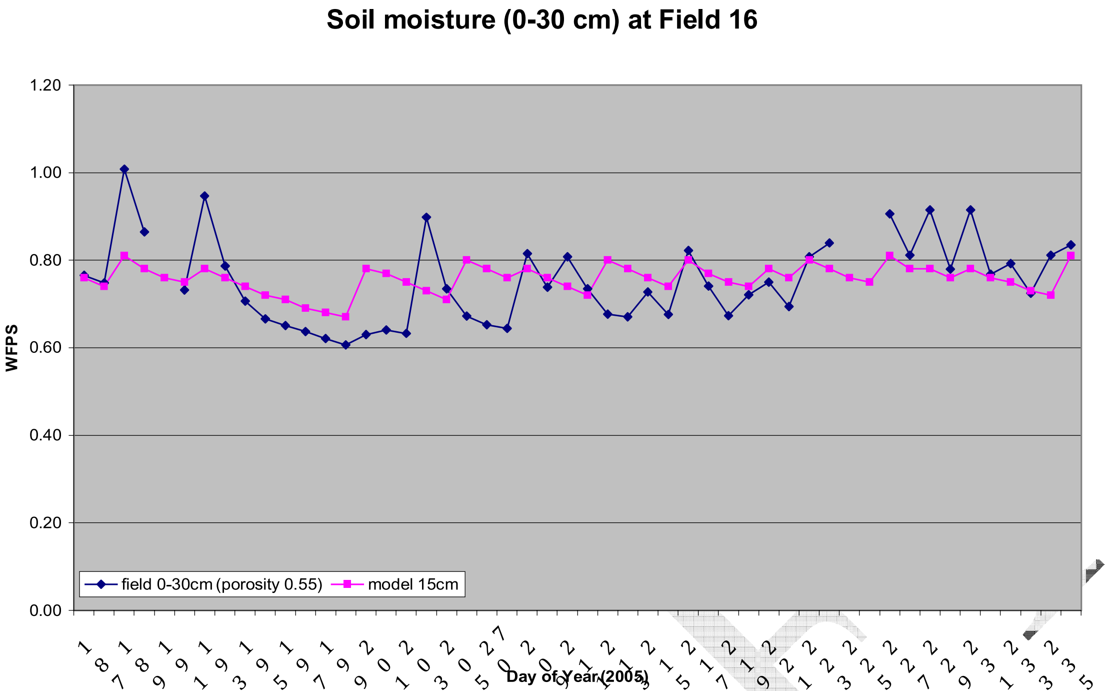

Figure 7 Comparison between modeled and measured soil moisture dynamics at a depth of 0-30cm.

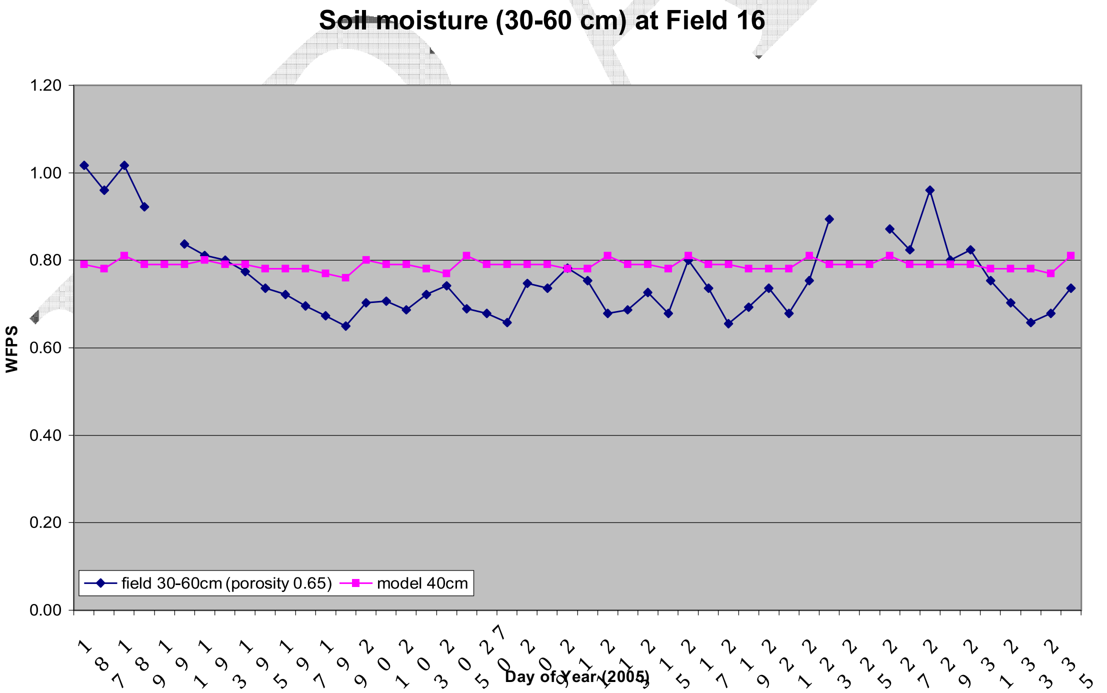

Figure 8 Comparison between modeled and measured soil moisture dynamics at a depth of 30-60cm.

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4.3 Soil Nitrate:

Soil nitrate data were collected on a weekly basis for both the control and BMP for each of the five field trials at 3 depths (0-33cm, 33-66cm, and 66-100cm). Based on the field measurements for the 2005 celery trial, nitrate concentrations were higher in the upper layer (0-33cm) for the control, but surprisingly were higher for the BMP trial in the deeper layer (33-66cm) (Figure 9)

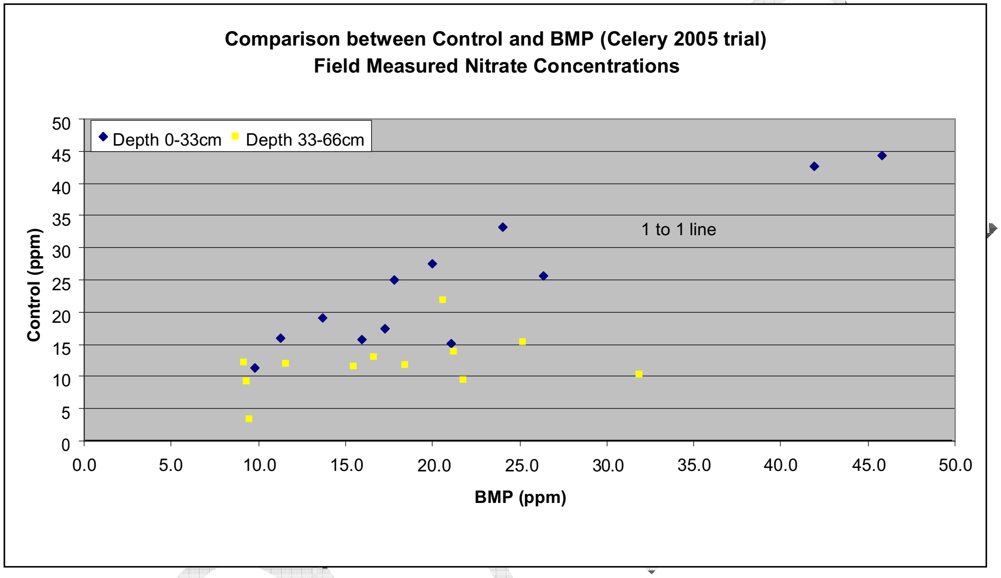

Figure 9 Comparison of nitrate concentration between control and BMP at two soil depths.

Figures 10-13 present the comparison between measured and modeled nitrate concentrations over the growing season.

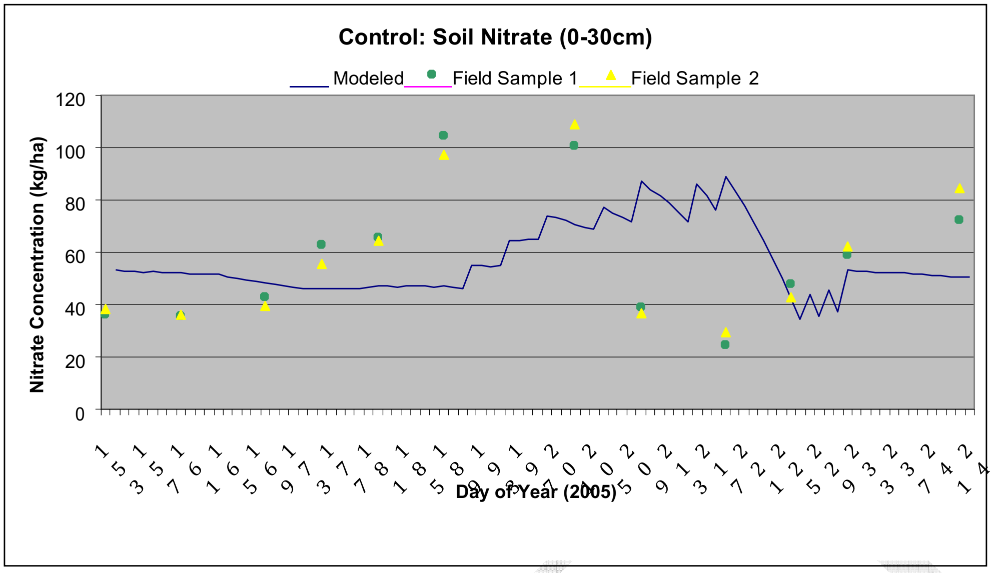

Figure 10. Soil nitrate content, Celery 2005 Trial, Control, 0-30cm.

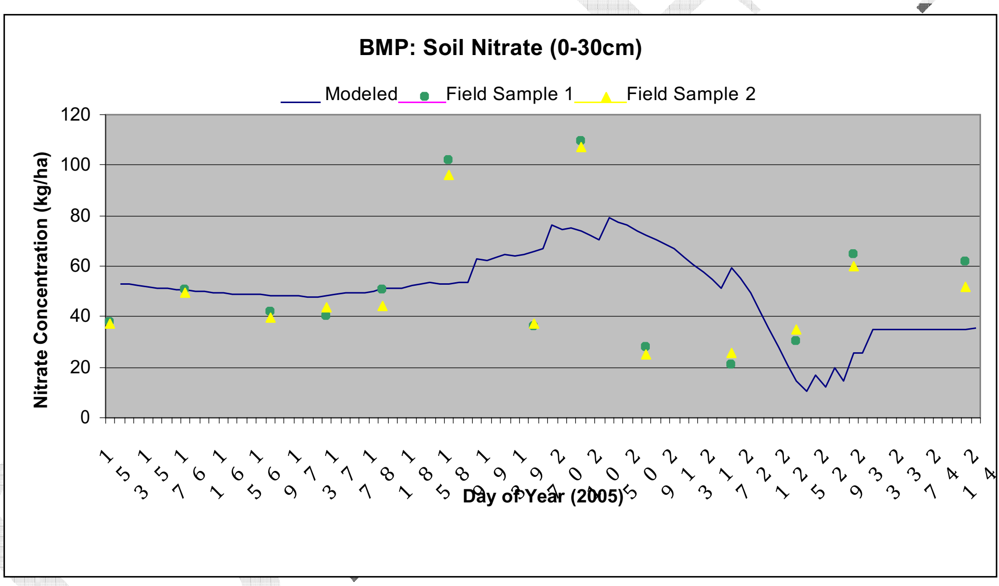

Figure 11. Soil nitrate content, Celery 2005 Trial, BMP, 0-30cm

For the top 30cm of soil, the modeled and field observed nitrate dynamics seem to be out of phase, with increases and decreases of nitrate occurring sooner in the field data. In addition, the magnitude of the changes is slightly higher in the field data than the modeled data. Nevertheless the model appears to follow the general trends of the field measurements. The two sites shared similar trends of nitrate variation within 0-30 cm, except for the measurement on DOY=199 at the BMP field, where field measured nitrate had a large decrease from the previous sample, followed by a large increase the following week.

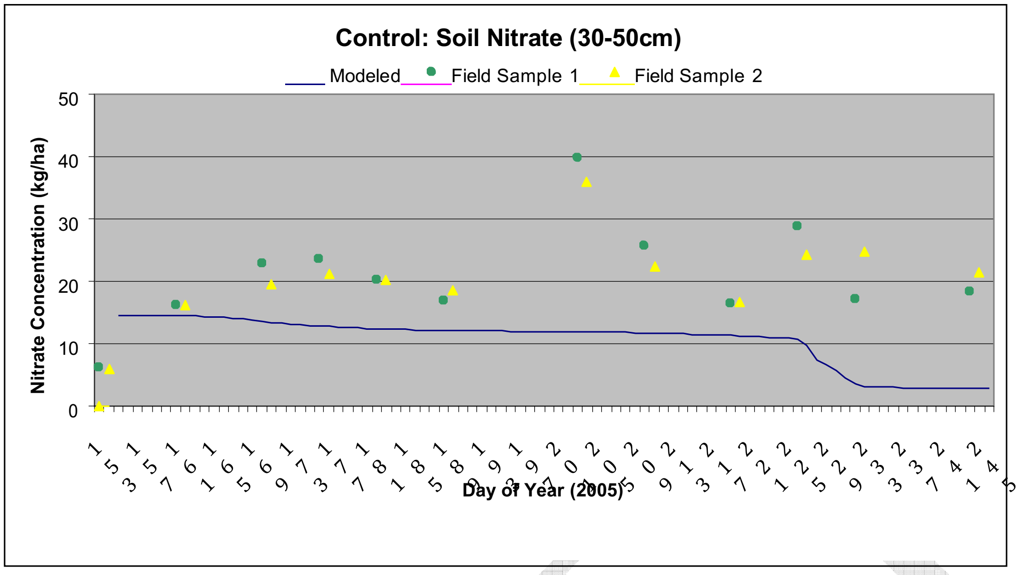

Figure 12. Soil nitrate content, Celery 2005 Trial, Control, 30-50cm

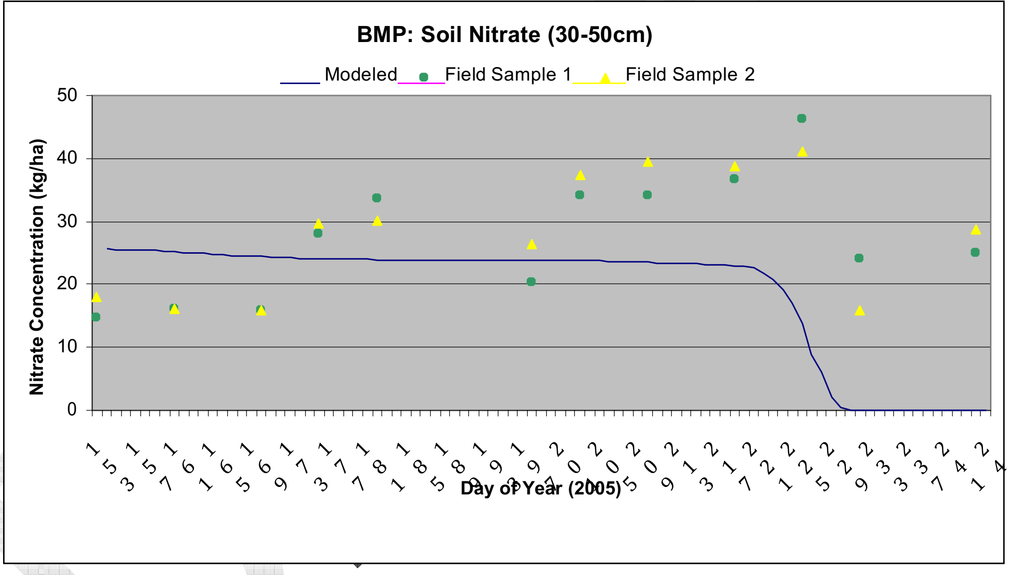

Figure 13. Soil nitrate concentration, Celery 2005 Trial, BMP, 30-50cm.

Modeled soil nitrate dynamics differed between BMP and Grower. For the deep soil layer (30-50cm) the BMP site had consistently higher soil nitrate concentrations. This is likely due to higher water leaching (also had more irrigation water) for the control site, resulting in less residual nitrate in the deep layers. That led to a nitrate leach rate (176 kg N/ha/yr) from the Grower field higher than that (112 kg N/ha/yr) from the BMP field.

5. Modeling Approach

Five trials for vegetable fields planted with baby-spinach, brussels-sprouts and celery were tested with the DNDC model for quantifying the impacts of different farming management practices (conventional grower practices or Control vs. best management practices or BMP) on nitrogen (N) dynamics in the agro-ecosystems in Central Coastal California. The modeling tests serve as a supplement to the field observations to understand N biogeochemical cycling under the specific climate, soil and management conditions.

The model input parameters were set based on the local climate from CIMIS stations, and soil, crop and management data collected by project collaborators (Drs. Michael Cahn, Marcus Buchanan and Marc Los Huertos). Observed inorganic N profiles were utilized to adjust the modeled soil N profiles during the simulations. The physiological and phenologic parameters for the baby-spinach, brussels-sprouts and celery crops were calibrated based on field-observed biomass and yield (see example in Figure 5). The parameters of the three crops adopted for this study are listed in Appendix 1, 2, 3 and 4.

DNDC was run for one year for each crop field with Control and BMP scenarios. Daily model results include crop growth, C and N cycling, trace gas emissions, and N leaching.

5.1 Model Parameterization of Best Management Practices

There were five sets of field trials for this project. The following provides a short summary of each trial and how the DNDC input parameters were set to simulate both control and BMP simulations.

5.1.1 Site 1 Celery 2005:

- Title: Best Management Practices (BMP) for Water and Nitrogen of Celery

  Growing Dates: 6/3/05-8/25/05

  Objective: Evaluate best management practices for water and nitrogen fertilizer management in celery.

  Best Management Practices Evaluated:

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- CIMIS weather based irrigation scheduling.
- Reduced N fertilizer applications

DNDC Simulations: the amount and timing of irrigation and fertilizer, as well as number and type of tillage events were varied to match the field applications of the control and BMP. Summary is provided in the following table:

Celery 2005	Control	BMP
# Fertilizer Applications	13	12
Total Fertilizer Applied (kg N/ha)	411.2	339.9
# Irrigation Events	24	28
Total Irrigation Water Applied (cm)	573	457
# Tillage Events	12	4

5.1.2 Site 2: Spinach 2005

- Title: Best Management Practices (BMP) for Reducing Run-off and Nitrate Leaching in Baby Spinach

Growing Dates: 9/15/05-10/17/05

Objective: Evaluate best management practices for water and nitrogen fertilizer management in Spinach.

Best Management Practices Evaluated:
- Polyacrylamide for improving quality of irrigation run-off

DNDC Adjustments: Soil properties are a main environmental control on soil biogeochemical processes. Polyacrylamide (PAM) reduces soil erosion, through improved formation of soil aggregates, and improves water infiltration. However, DNDC cannot simulate the effects of PAM directly. Therefore, we used the field based measurements of runoff for both the control (no PAM) and the BMP, to adjust the effective amount of irrigation (amount of irrigation water that infiltrated the soil surface) by reducing the irrigation applied by the runoff. Summary is provided in the following table:

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Spinach 2005	Control	BMP
Total Effective Irrigation Water Applied (cm)	134	229

5.1.3 Site 3: Celery 2006

- Title: Best Management Practices (BMP) for Water and Nitrogen of Celery

Growing Dates: 5/18/06-8/10/06

Objective: Evaluate best management practices for water and nitrogen fertilizer management in celery.

Best Management Practices Evaluated:
- CIMIS weather based irrigation scheduling.
- Reduced N fertilizer applications

DNDC Simulations: the amount and timing of irrigation and fertilizer were varied to match the field applications of the control and BMP. Summary is provided in the following table:

Celery 2006	Control	BMP
# Fertilizer Applications	11	19
Total Fertilizer Applied (kg N/ha)	740.4	436.2
# Irrigation Events	33	33
Total Irrigation Water Applied (cm)	1854	1597

5.1.4 Site 4: Baby Spinach 2006

- Title: Best Management Practices (BMP) for Reducing Run-off and Nitrate Leaching in Baby Spinach

Growing Dates: 7/22/06-8/12/06

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Objective: Evaluate best management practices for water and nitrogen fertilizer management in Spinach.

Best Management Practices Evaluated:

- Polyacrylamide for improving quality of irrigation run-off

DNDC Adjustments: Soil properties are a main environmental control on soil biogeochemical processes. Polyacrylamide (PAM) reduces soil erosion, through improved formation of soil aggregates, and improves water infiltration. However, DNDC cannot simulate the effects of PAM directly. Therefore, we used the field based measurements of runoff for both the control (no PAM) and the BMP, to adjust the effective amount of irrigation (amount of irrigation water that infiltrated the soil surface) by reducing the irrigation applied by the runoff. Summary is provided in the following table:

Spinach 2006	Control	BMP
Total Effective Irrigation Water Applied (cm)	116	127

5.1.5 Site 5: Brussels Sprouts 2006

- Title: Best Management Practices (BMP) for Reducing Nitrate Leaching in Brussels Sprouts

Growing Dates: 6/28/06-12/05/06

Objective: Evaluate best management practices for water and nitrogen fertilizer management in Brussels Sprouts.

Best Management Practices Evaluated:

- Drip irrigation
- Reduced N fertilizer applications

DNDC Simulations: the depth (for drip we assumed a depth of 15cm, otherwise it was surface applied) and number of irrigation applications and number and amount of fertilizer applied were varied to match the field applications of the control and BMP. Summary is provided in the following table:

Brussels Sprouts 2006	Control	BMP
# Fertilizer Applications	4	16

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Total Fertilizer Applied (kg N/ha)	346.9	304.8
# Irrigation Events	16	22
# Tillage Events	7	6

We have included all of the DNDC input files, daily model results, and CIMIS weather data for 2005 and 2006 on the project CD-ROM.

6. Results and Discussion

Based on the modeled annual and daily results, analyses are presented for both the crop seasonal period and the entire model year. We present the annual results because the impacts of varying management practices affect N dynamics not only during the cropping season period, but also the period following crop harvest. The annual and seasonal modeled results are summarized in Tables 1 and 2 below, respectively. These tables summarize the total N balance for each trial, including inputs, crop uptake, leaching and gas emissions (NH_3 volatization, N_2O, NO and N_2 emissions). The results indicated that the shift of management from Control to BMP could alter not only the crop yields but also nitrate leaching as well as N gas emissions for the modeled vegetable fields.

6.1 Annual analysis

Since impacts of any farming practice, which is applied within a crop season, will always last beyond the season, analyses based on the simulated annual results were conducted to observe the differences induced by the Control and BMP management scenarios. As the land-use conditions before the crop season were treated same (i.e. bare soil without any farming activity), the annual differences must come from the management practices in the crop seasons.

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6.1.1 Celery in 2005

The BMP and Control sites shared same climate/soil conditions and farming management practices except fertilization and irrigation rates. 339.9 and 411.2 kg N/ha were applied for BMP and Control, respectively. 457 mm of water was applied with 28 irrigation events for BMP; and 573 mm of water applied for Control with 24 irrigation events. By shifting management from Control to BMP, crop yield decreased slightly from 1998 to 1944 kg C/ha, nitrate leaching rate decreased from 60.3 to 36.7 kg N/ha, and N2O emission rate decreased from 4.27 to 3.14 kg N/ha. These results indicate that splitting the irrigation and fertilizer application events resulted in only a minor drop in yield while lowering the release of reactive nitrogen to the environment.

6.1.2 Baby spinach in 2005:

The BMP for this trial was the use of PAM to decrease the amount of surface runoff and enhance infiltration of irrigation. The BMP and Control sites shared same climate/soil conditions as well as farming management practices except effective irrigation (229 mm for BMP vs. 134 mm for Control). A fertilizer mixed with nitrate and ammonium sulfate was applied at rate 162.2 kg N/ha to support the crop growth, which demanded 85 kg N/ha under optimum growth conditions.

In comparison with Control (crop yield 378 kg C/ha with N leaching rate 44.6 kg N/ha), BMP had higher crop yield (406 kg C/ha) and also higher nitrate leaching rate (56.6 kg N/ha) mainly due to better irrigation water infiltration (effective irrigation rate) due to use of PAM. The emissions of nitrogen gases (e.g., NH3, N2O, NO, N2) were negligible for both sites. A significant amount of nitrate (>100 kg N/ha) existed in both the BMP and Control soil profiles during and after the growing season that created favorable conditions for nitrate leaching. While the higher effective irrigation rate at the BMP site caused more nitrate leaching, this negative consequence of using PAM can be ameliorated by adjusting the total irrigation water accordingly.

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6.1.3 Celery in 2006

The BMP and Control sites shared same climate but different soil conditions (SOC 0.0071 vs. 0.0084 kg C/kg for BMP and Control). The fertilizer application rates were 436.2 and 740.4 kg N/ha for BMP and Control, respectively. The irrigation rates were 1597 and 1894 mm for BMP and Control, respectively. By shifting management from Control to BMP, crop yield decreased from 1875 to 1795 kg C/ha, nitrate leaching losses decreased from 406.9 to 195.9 kg N/ha, and N2O emission rates decreased from 5.07 to 1.97 kg N/ha. Again, these results indicate that splitting the irrigation and fertilizer application events resulted in only a minor drop in yield while lowering the release of reactive nitrogen to the environment.

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6.1.4 Baby spinach in 2006:

The BMP for this trial was the use of PAM to decrease the amount of surface runoff and enhance infiltration of irrigation. The BMP and Control sites shared same climate/soil conditions as well as farming management practices except effective irrigation (127 mm for BMP vs. 116 mm for Control). The modeled results between BMP and Control were very similar only with slight differences in yield and N leaching loss. In comparison with the results for 2005, the same fields had much less N leaching losses (44.6-56.6 kg N/ha for 2005 vs. 2.0-3.2 kg N/ha for 2006) with only a slight cost in the crop yield. The significant decrease in N leaching rate for both the control and BMP in 2006 compared to 2005 was due to the lower precipitation, decrease in irrigation rate and lower fertilizer application rates.

6.1.5 Brussels sprouts in 2006

The BMP and Control sites shared same climate/soil conditions and farming management practices except amount of fertilization, number of fertilizer applications and number of irrigation events. For BMP, 304.8 kg N of synthetic fertilizer was applied with 16 applications mostly at depth 15 cm; and for Control, 346.9 kg N/ha of fertilizer was applied with 4 applications at the soil surface in the early season and 15 cm depth in the late season. The timing of fertilizer application caused substantial differences in crop yield and nitrate leaching rate. Both the BMP and control had the same amount of irrigation (311mm), but the BMP and control had 22 and 16 irrigation events, respectively. The modeled crop yields were 2308 and 1626 kg C/ha for BMP and Control, respectively. By shifting management from Control to BMP, the nitrate leaching rate decreased by 57% and N2O emission flux decreased by 41%.

The results indicated that splitting the irrigation and fertilizer application events and applying the fertilizer in deep soil layers substantially increased the fertilizer use efficiency, resulting in a lower release of reactive nitrogen to the environment.

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6.2 Seasonal analysis

The simulated N flux data within time spans of the crop growing seasons were extracted for seasonal analysis. Several major N input and output fluxes modeled during the crop growing seasons are summarized in Table 2. The extracted data can show the N inputs and outputs during the growing seasons from planting date to harvest date but don't provide the information of the off-season effects of the farming practices taking place during the preceding cropping season. For example, a post-season heavy rainfall could cause a surge of nitrate leaching from a field with higher amounts of residual soil nitrate from fertilizer. The simulated N leaching data within the season won't reflect this impact.

For the 2005 spinach trial, there was an increase of N leaching from 4.7 to 25.5 kg N/ha by using PAM, an increase of approximately 20 kg N/ha. However, if we compare the total leaching throughout the year, the PAM application caused an increase of only 12 kg N/ha, because the higher residual nitrate (less water leaching due to PAM) from the control site was leached following the cropping season. However, for some management systems (e.g. 2006 Celery trial) with high fertilizer applications high coupled with large amount of irrigation water, or heavy rains, much of the nitrogen inputs can be exported during the growing season (e.g. compare annual and seasonal N leaching for 2006 Celery crop). Therefore, assessing the efficacy of a set of BMPs should consider not only N impacts during the growing season, but also the N legacies of those management decisions.

7. Summary and Next Steps

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The modeled results, especially from the annual analyses, indicate that

(1) Nitrate leaching is the major path leading to N losses from the vegetable fields in the tested sites in Santa Clara Valley, California. Over-fertilizing and over-irrigating are the main management issues enhancing nitrate leaching.
(2) There are potentials to reduce the nitrate leaching through alternative management practices. The modeled BMP scenarios decreased nitrate leaching due to a) reduced application rates of fertilizer and/or irrigation water, b) altered timing of the applications, and/or c) increased depth of fertilizer application. The alternative management practices substantially elevated the fertilizer or water use efficiency for the vegetable fields and hence moderate their negative impacts on the environment.
(3) While use of PAM can reduce irrigation water runoff, rates of irrigation water application should be adjusted to compensate for the better infiltration to avoid enhanced leaching.

This report was prepared based on one-year simulations. Since a great amount of residue inorganic N left in the soil profiles by the end of the simulated years for most of the modeled fields, the effectiveness of the BMP scenarios on reducing nitrate leaching should be greater if the multi-year impacts are counted. The estimates presented in this report are conservative.

Based on our model testing at these sites, the model appeared to capture the temporal dynamics soil N cycling, however, given the differences in magnitude of the change, the model should be used for qualitative analyses of impacts of management on N leaching. Further research and analysis with these existing datasets will increase our understanding of the weaknesses and strengths of the DNDC model for this particular application. The DNDC model was originally designed as a biogeochemical model, which mainly deals with the microbe-induced processes for the upper layer of soil. Nitrate leaching is a phenomenon controlled by both biogeochemical and hydrological conditions. Though DNDC has been modified to try handling more hydrological processes (e.g., discharge retention, deep water storage etc.), the model still has difficulties in modeling deeper hydrological processes that may be driven by different soil or geological structures beyond the model input information. However, when evaluating the long-term impacts of agricultural management, it is most important to be able to evaluate soil nitrate dynamics in the upper soil layer, because once nitrate moves to the deeper layers it is likely to be leached in the long run.

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8. Tables

Table 1. DNDC-modeled annual soil N pools (kg N/ha) and fluxes (kg N/ha/yr) for baby spinach, Brussels and celery fields with grower practices (Control) and best management practices (BMP) at Santa Clara Valley, California

Crop field	Baby spinach 2005		Baby spinach 2006		Brussels sprouts, 2006		Celery, 2005		Celery, 2006	
Management scenario	Control	BMP	Control	BMP	Control	BMP	Control	BMP	Control	BMP
Soil N pools^{+}										
-IniSON	1274.9	1274.9	1274.9	1274.9	4151.0	4151.0	2479.8	2479.8	2046.2	1729.5
-IniSIN	6.4	6.4	6.4	6.4	21.0	21.0	12.5	12.5	10.4	8.8
-EndSON	1268.6	1268.8	1266.6	1266.6	4130.2	4133.3	2497.1	2481.8	2029.1	1716.9
-EndSIN	168.3	113.8	77.3	98.3	192.2	92.4	164.9	156.0	158.0	65.0
-AdjSIN*	97.1	57.8	-21.8	8.2	70.6	91.6	1.5	18.7	37.3	28.9
-Input fluxes										
--Atmo/irri deposit	5.5	6.5	3.6	3.7	10.1	9.85	9.6	8.5	20.4	17.9
--Fertilization	162.2	162.2	143.9	143.9	346.9	304.8	411.2	339.9	740.4	436.2
--Litter incorporation	7.9	8.5	0.5	0.5	30.7	43.6	114.6	111.5	30.9	29.5
--Manure amendment	0	0	0	0	89.6	89.6	0	0	0	0
-Output fluxes										
--Crop uptake	70.1	75.3	58.9	63.1	312.5	443.6	296.3	288.2	278.1	266.1
--NO3 leaching	44.6	56.6	2.0	3.2	73.2	31.4	60.3	36.7	406.9	195.9
--NH3 volatilization	2.03	1.33	0.71	3.28	1.15	0.34	1.98	1.63	2.21	0.89
--N2O emission	0.72	0.49	1.22	2.11	7.76	4.60	4.27	3.14	5.07	1.97
--NO emission	0.43	0.33	0.65	0.85	1.49	1.71	2.22	1.55	2.37	1.00
--N2 emission	0	0	0.01	0.03	0.90	0.64	0.30	0.21	0.84	0.41
Error in N balance**	-0.78	-0.35	0.12	0.16	1.4	4.1	2.13	1.88	3.85	3.04
Crop yield, kg C/ha	378	406	310	332	1626	2308	1998	1944	1875	1795
Precipitation, mm	632	632	424	424	877	877	632	632	424	424
Irrigation water, mm	134	229	116	127	311	311	573	457	1854	1597
Evapotranspiration, mm	368	370	335	338	531	589	603	600	586	586
Leached water, mm	341	433	207	215	639	581	456	345	1675	1426

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$^{+}$IniSIN (initial soil inorganic nitrogen), IniSON (initial soil organic nitrogen), End SIN (final SIN), EndSON (final SON)

* AdjSIN: Increase or decrease in SIN due to altering the soil inorganic N profiles with observed SIN data;

** Error in N balance = (IniSON+IniSIN+AdjSIN+Atmo/irri depositi+Fertilization+Litter incorporation+Manure amedment) – (EndSON+EndSIN+Crop uptake+NO3 leaching+NH3 volatilization+N2O+NO+N2 emissions).

Table 2. DNDC-modeled seasonal soil N fluxes (kg N/ha/yr) for baby spinach, Brussels and celery fields with grower practices (Control) and best management practices (BMP) at Santa Clara Valley, California

Crop field	Baby spinach 2005		Baby spinach 2006		Brussels sprouts, 2006		Celery, 2005		Celery, 2006	
Management	Control	BMP	Control	BMP	Control	BMP	Control	BMP	Control	BMP
Season span	9/13–10/17		7/16-8/12		7/16-11/20		6/2-8/29		5/19-8/15	
Soil N fluxes										
-Input fluxes										
--Atmo/irri deposit	1.1	2.1	0.95	1.05	2.55	2.70	5.1	4.1	17.4	14.9
--Fertilization	162.2	162.2	100.2	100.2	253.5	247.7	323.8	252.5	667.6	363.4
--Litter incorporation	0	0	0.45	0.48	28.09	39.9	20.8	20.2	19.5	18.7
--Manure amendment	0	0	0	0	0	0	0	0	0	0
-Output fluxes										
--Crop uptake	70.1	75.3	58.9	63.1	312.5	443.7	296.3	288.3	278.1	266.1
--NO3 leaching	4.7	25.5	0.01	1.18	10.98	0.0	36.14	18.4	399.5	191.4
--NH3 volatilization	1.1	0.77	0.63	2.61	0.76	0.01	1.12	0.94	1.8	0.65
--N2O emission	0.55	0.42	0.94	1.53	5.55	2.76	3.74	2.57	4.25	1.7
--NO emission	0.31	0.25	0.57	0.74	1.21	1.57	1.92	1.32	2.02	0.89
--N2 emission	0	0	0	0	0.49	0.17	0.19	0.12	0.74	0.35

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10. Appendices

Appendix 1: Crop parameters for celery

22	crop_code
Celery	crop_name
3448.28	total_biomass_C
0.58	portion_of_grain
0.30	portion_of_shoot
0.12	portion_of_root
11.627900	plant_CN
11.000000	grain_CN_ratio
20.000000	root_CN_ratio
11.000000	shoot_CN_ratio
300.000000	water_requirement
3.000000	max_LAI
0.500000	max_height
1500.000000	TDD
1.0	N_fixation

Appendix 2: Crop parameters for baby-spinach-2005

52	crop_code
Baby_spinach	crop_name
592.778015	total_biomass_C
0.720000	portion_of_grain
0.100000	portion_of_shoot
0.180000	portion_of_root
7.301840	plant_CN
6.800000	grain_CN_ratio
11.000000	root_CN_ratio
6.800000	shoot_CN_ratio
300.000000	water_requirement
3.000000	max_LAI
0.500000	max_height
403.000000	TDD
1.0	N_fixation

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Appendix 3: Crop parameters for baby-spinach-2006

53	crop_code
Spinach2	crop_name
507.847992	total_biomass_C
0.790000	portion_of_grain
0.150000	portion_of_shoot
0.060000	portion_of_root
6.122450	plant_CN
6.000000	grain_CN_ratio
9.000000	root_CN_ratio
6.000000	shoot_CN_ratio
300.000000	water_requirement
3.000000	max_LAI
0.500000	max_height
600.000000	TDD
1.0	N_fixation

Appendix 4: Crop parameters for Brussels-sprouts

37	crop_code
Brussels_sprout	crop_name
4991.879883	total_biomass_C
0.640000	portion_of_grain
0.200000	portion_of_shoot
0.160000	portion_of_root
8.127800	plant_CN
7.500000	grain_CN_ratio
14.500000	root_CN_ratio
7.500000	shoot_CN_ratio
400.000000	water_requirement
4.000000	max_LAI
0.500000	max_height
1670.000000	TDD
1.000000	N_fixation

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